A PROGRAM OF OPERATIONS RESEARCH FOR THE STATE OF MARYLAND

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I. EXECUTIVE SUMMARY

The State of Maryland should initiate a program of operations research/systems analysis/econometrics/planning/multi-disciplinary problem-solving in at least two ways:

(1) Augment the existing, but small, use of time-tested analytic procedures of inventory control, equipment replacement studies, linear programming, and economic forecasting, in various departments of the Executive Branch of the State Government. This should be accomplished with the addition of about five operations research analysts distributed to the staffs of existing agencies, and through an increased use of the Maryland universities.

(2) Develop a management exercise (game or simulation) to assist agencies to address themselves collectively to the interacting expected consequences of their individual plans, to the end that the goals of the State are more fully realized as a result of collective thoughtfulness about the future. The University of Maryland's Bureau of Business and Economic Research should serve as the initial focal point for this work.

The text of this report elaborates still further opportunities for the exercise of other operations research techniques.

Finally, and more importantly, a State government provides a unique opportunity to develop the systematics of the management sciences to problems that involve multiple-connected jurisdictions, the complementarity of goals, the emergence of new aspirations of man, and a direct test of the best way to turn the new management science methods to the support of the democratic system of rebuttal and debate.

II. INTRODUCTION

A. Purpose

On March 22, 1966, Governor Millard Tawes addressed the Maryland General Assembly on the subject of the Modernization of the Executive Branch of the State Government. Among the challenges that he voiced was the following:

"Still another way--a most exciting way--in which the Executive Branch of our State government can be better geared up for the tasks ahead is by bringing the vast new scientific technology of operations analysis and systems engineering to bear on the basic problems of this State.

"Business organizations have already pioneered the use of the latest analytical techniques and electronic tools on their more difficult challenges. Our State government has begun to utilize computer data processing to assist on the voluminous statistical compilations and computations of various State agencies.

"But we must make far greater progress--and the Legislature must recognize the need for supporting funds--to bring these new skills and resources to bear on the really stubborn and sophisticated problems that confront us."

The Governor subsequently asked his Science Resources Advisory Board to outline for him a proposed program of action whereby the Executive Branch of the State Government might make maximum use of these new technologies of operations research and systems engineering:

"More specifically I would like you to direct these studies toward determining how the Executive Branch of our State Government might better discharge its future responsibilities through the use of operations analysis and systems engineering. I mention these two in a broad sense since it is intended that the Board explore the application of interdisciplinary scientific approaches for this purpose."

The Science Resources Advisory Board convened on 13 May 1966 to lay out the plan for responding to the Governor's request. At that time it was determined that it would be possible to perform a surgical separation of the computer and ADP study and the program for operations research for purposes of analysis.

Inasmuch as operations research is strongly dependent upon the computer for much of its calculations, and since the computer community is well aware of the needs for operations research, it appeared that this surgical separation could be rejoined rather easily following completion of the analysis, since both parties were aware of the ultimate need for a reconnection, and since much of the developing work of the committee was done side by side.

This appendix is therefore the report on the proposed program of operations research for the State of Maryland.

In this report, the phrase, "Operations Research", will be used to designate a rather broad family of activities for which designations such as "operations analysis," "systems analysis," "systems engineering," "planning," and "multidisciplinary problem-solving teams," are members. Although each of these traditions has its own special attitudes and subject matter, the intent of this report is to consider the collective utility of the various analytic schemes and attitudes that have been developed under these various banners in the past several decades. Indeed, the growth of these procedures that were intended to introduce a more meaningful use of the scientific methods in the decision-making context has been so rapid that it is not fully clear whether operations research and other members of its immediate family are best characterized as art, science, or attitude. It is probably fair to say that it is something of all three. It has enjoyed rapid growth, partly because of its audacity, its patience, and its practicality. Its audacity has been expressed in terms of tackling man's most severe problems of daring to raise questions concerning matters that have been sacred folklore in the past, and in daring to suggest that improved performance or lower cost would readily follow a sharing of responsibility by two competing agencies. Its patience was expressed in terms of its willingness to lay out a series of explicit alternative courses of action and patiently to accumulate the data concerning the expected natural consequences of each when confronted with a variety of alternative environments, and when laying out courses of action that were available to those whose interests were contrary to those of the interests of the agency whose problem was being formulated. It was expressed in the ability to lay out a simple calculating procedure that would enable one systematically to compute the implications of the sets of data thus compiled. It was practical in that during the heat of World War II and afterward, a large fraction of its practitioners was willing to postpone the development of highly desirable theory in favor of rolling up its sleeves and assisting in the solution of the problem that was most pressing at the time.

Many would say that operations research was not a new phenomenon at all; that indeed, executives have always requested scientific advice, and that good scientists have always considered as many possibilities as were reasonable, and faithfully and objectively evaluated their expected consequences. It is true that a large volume of the mathematical techniques of operations research is a direct building upon the inventory control formulas and the machine replacement calculations that were developed prior to the initiation of hostilities in WWII, and it is certain that man has always been thoughtful about laying out his future.

B. Criteria

In order that the reader may properly evaluate the proposed program of action in the document that is to follow, it is important that a number of convictions of the author be aired at the outset, since they have served the purpose of being assumptions concerning the nature of the State of Maryland's operations research program.

(1) The basic problem is to determine how to build on, and modify where appropriate, the capital investment already made by the Department of Defense and American industry in the United States and on the investments of comparable institutions in other nations of the world. It must also build upon existing procedures now being used in the State of Maryland, rather than starting from scratch.

(2) The proposed program should provide the raw materials for the exercise of multiple choice by the people who will decide whether and what kind of operations research programs to inaugurate into the State. An entire panorama of possibilities ranging from small and very practical extensions of existing procedures to an imaginative and elaborate scheme of research should be included. A preferred research strategy should be indicated, but the ability to reconstruct a different implementation strategy should be preserved.

(3) One of the central lessons of Plato's Republic must be at work. This lesson is that one should search for the least change that needs to be introduced into a system, with all its cultural backgrounds and all of its compensating mechanisms, that would have as a natural consequence that the adaptive nature of the citizens and the institutions would respond to create a better future. By way of contrast, the proposed innovations should not entail a wholesale reorganization of the wide variety of institutions and activities that had been established in the past.

Needless to say, the mathematical and other procedural rules for identifying the least change have not been developed. Yet it is in this area that some of the most outstanding successes of operations research have been apparent. One example of this is that provided by Professor Charles Warren Thornthwaite of the Johns Hopkins University for the Seabrook Farms in southern New Jersey. In this case, Professor Thronthwaite developed a calendar of growth units for each of the vegetables produced by Seabrook Farms and instituted a procedure that eliminated a wide variety of social problems caused by the import of transient labor, etc. 1/

(4) The program proposed here must be intensely practical in nature, with a view to providing enough immediate payoffs (three months, six months, 1 year), to warrant the conclusion that the program is well worth the investment of scarce resources required to initiate it in a meaningful way. Although intensely practical, it must be guided in an idealistically inspired manner. It must, in the final analysis, dare to ask the question, "What are the goals of the State of Maryland, and what should they be?" "What are the goals of the citizens of Maryland and what should they be?" "What is the proper purpose of the institutions of the State and what is the proper meaning of the discharge of public responsibility?"

(5) Most of the developments in the field of operations research have been related to the military or industrial establishments. In those cases, it is possible to identify either a measure of value (profitability for industry) or to identify a number of indicators, each of which is uniquely related to a rather monolithic scale of values (fire power and maneuverability as indicators of defense readiness). The program proposed here, therefore, must be aware that the programs of a State ~~have~~ a mission that is probably imperfectly expressable either in economic or military terms. The concept of Gross National Product per person or net state income per person, even when considered as distributed among the state's citizens by socio-economic strata, is probably inadequate to serve as more than the first approximation to measures of worth of programs intended to raise the standard of living of the citizens of the state.

1/ C. W. Thornthwaite, "Operations Research in Agriculture", Operations Research for Management, edited by Joseph F. McCloskey and Florence N. Trefethen, The Johns Hopkins Press, 1954.

(6) The program proposed here must be developed with an awareness that these non-defense goals of the programs of the State of Maryland have many complementary aspects. There is the desire for more open space and yet there is a desire to spread cities out. There is a desire for leisure and quiet, and there is a simultaneous desire for highspeed throughput of traffic. Operations research theoretitions, in common with their economist counterparts who consider social welfare functions, have mused upon possibilities of creating a scalar measure of value for different programs. There must be in this proposed program of operations research an awareness that measures of utility will have many ways of expressing themselves.

(7) The program must be developed in such a way as to be aware of the fact that the setting of levels of acceptability for goal achievement in the State and the setting of acceptable levels of resource investments (taxes) is distributed among the electorate of the State. It must also be recognized in the layout of such a program that the wishes of the electorate are expressed through representatives who propose and execute the program as a proxy of the public. It must also be recognized that the question will ultimately arise concerning the distinction between those things that an institution wants and those things that an institution ought to want.

(8) The program must be developed with an awareness that a state has special characteristics that have been built up over a long period of time; that it has a strong cultural heritage and that before a nation was created, the state was a focus of sovereignty. Just as there can be no monolithic scale of values with respect to determining program preferences in a scalar way, the state OR program must not unknowingly commit the logical fallacy of division (what is true of the whole is true of each part).

(9) The program of operations research must be developed with an acknowledgement that many federal programs dedicated to the improvement of the quality of life to the American citizens and of the American community will be carried out using the State Government as the executive agency for those programs. The workload on the State in the future, then, is likely to expand in direct proportion to federally conceived programs for the improvement of the nature of American life in general, and toward the selective improvement of particularly disadvantaged segments of American life in particular. From a federal point of view, when a state acts as an agent in improving the quality of life, it has both a focusing and dissipating characteristic. When

sensitively related to the needs of individual citizens and communities, a state can transform federal financial resources into a really productive program, potentially surpassing the fondest hopes of the most understanding designer. At the other extreme, it becomes possible to degrade or dissipate the effectiveness of a program as intended in its earlier blueprint. The OR program proposed for the State, therefore, must be aware of the expected growth in federally sponsored programs, including the fact that various bills have been introduced to the Congress whose explicit purpose is to stimulate the growth of systems analysis at the state level, e.g., HR-11663 and SZ-662.

(10) The program must recognize that a state is a set of counties, a set of cities, and a hinterland with natural resources. A state is a part of a larger organism, a river basin, a multi-state region, and a transportation corridor. It is both an importer and an exporter of goods, services, and culture. It competes with and cooperates with its sisters. Yet, as a state, its political boundaries easily define a locus of pride.

(11) The program proposed must not be deflected by the fact that it is relatively clear how to set up a large-scale computer based information system, and its course of action should not be uniquely determined by this impulse. Yet it is clear, that the assembly and interpretation of the implications of raw data results in one of the most valuable assets that a decision-maker or operating manager can have, and that OR will need a data system to make its calculations useful.

(12) The operations research program proposed here should not be critically dependent on any one single organizational structure of the executive branch of the state government.

(13) Finally, the operations research program as proposed, must recognize that there are certain number of characteristics of the State of Maryland that distinguish it from some of its sister states. It has a very high per capita income, it is located near the southern end of a very fast moving transportation corridor, it is both urban and pastoral, it has a wealth of recreational opprotunities, largely undeveloped, it has enjoyed a growth of the research and service industries that parallels the explosive economic growth of the state. It has an ability to be able to select among various tax alternatives, and is in a relatively unique position of being able to afford the luxury of

determining how to channel these resources into a significant leadership position over many decades in the future in terms of many quality characteristics. The OR program proposed, therefore, should build upon the notion that Maryland will adopt a leadership rather than a following position.

C. Operations Research, Systems Analysis, Management Science History

The phrase, "operational research," was coined in 1938 in the United Kingdom to describe a kind of research activity that had developed out of wartime necessity. When electronic engineers and physicists invented the radar set as a means of detecting incoming enemy raids and their product had been delivered to the British defense establishment, the natural second generation question to arise was that of how properly to deploy these radar sets to their best defensive advantage and how to use them properly in the midst of a military operation. The British Coastal Command prevailed upon the hardware scientists who had developed the electronic gadgetry to tarry a while with the military user to assist him in turning the invention to the advantage of the defense of the British Isles. Notice that a number of nontechnical questions were immediately invoked. Although it was possible to describe the geometry of the British Island, and the geometry of the coverage of a radar set, even though garbled by ground clutter and interference patterns, it was in theory, possible to lay out an arrangement of these radar sets coverage diagrams in sueh a way that maximum coverage of the British coastline would be provided and to determine that least number of radar sets that would provide it. The problem was complicated by a number of other issues. There was not a full-fledged inventory of such radar sets instantly available and they would have to be installed in series. Futhermore, the purpose of the incoming attackers was directly opposite to the purpose of the radar sets, and this was to avoid discovery as long as possible. Therefore it would be to the advantage of the incoming bombers to destroy the radar sets as they were installed, thereby reducing their effectiveness to zero. The problem was therefore one not of technological dimensions, but of building the technology into an operating system. This kind of research came to be known by the rather deprecating name of operations research to contrast it with the more precise hardware research. One conclusion emerged rather rapidly from the research that was conducted into the question of where to locate the radar sets, and this was that the net effectiveness of the radars was more dependent upon the length of time it took to transmit the messages back from the radar sets that an incoming attack had been detected, than it was to improve by even large amounts the technical operation of the set itself. Accordingly, the operations analysts turned their attention to ways of improving the speed of transmission of alert warnings along the telecommunications channel from the radar set back to headquarters. This resulted in a number of procedural improvements, as well as improved priority systems for handling messages. The next thing that became apparent was that the delivery of the message concerning an incoming attack, could be very timely, but that the defensive alert posture of the fighter command fighters at the airport had more to do with the effectiveness of intercepting an incoming raid than did any other remaining untouched variable, and so the operations analysts spread out to cover questions concerning alert procedures for the fighter command. By the end of the war, it was generally conceded that this new type of research had contributed rather significantly to the winning of the Battle of Britain. Because of their curiosity into affairs that seemed not immediately germane to the technical problem at hand, these operations analysts came to be known in the United Kingdom as "boffins," being described as a sort of very curious bird who poked his nose into everyone's business, but who ended up sometimes laying eggs and sometimes creating a totally new discovery about how to improve an operation.

Among the kinds of problems that these scientists began to solve are several listed by PMS Blackett in writing about the history of operations research in WWII;1/ the summary that follows is taken from some informal writings of Dr. Reginald Hobbah.

In defending London, was it better to deploy a limited supply of 120 guns in 30 four-gun AA batteries, or in 15 eight-gun batteries? Eight-gun batteries halved the area of London covered; but radar was available for only half of the 30 four-gun batteries. (The eight-gun battery won out.)

Explain why coastal AA batteries were more effective in shooting down enemy bombers--"less rounds per bird"--than the inland batteries were. (They weren't. Overestimates by inland batteries were corrected when claimed aircraft could not be found; when coastal batteries claimed to have shot the bombers into the sea, the claims went uncontested.)

Determine the best depth setting for depth bombs dropped by Coastal Command aircraft against U-boats. (Settings were reduced from 100 feet to 25 feet; U-boat crews reported that the British had produced a new, more powerful explosive.)

1/ Studies of War, Hill & Wang, New York, 1962.

Which was more useful? To use a long-range bomber to save six merchant vessels from sinking in the Atlantic? Or use it to kill two dozen men, women, and children, and destroy a number of houses, in Berlin? (Blackett says there was no argument over relative values; the problem was to get Whitehall to believe that these figures represented the average lifetime accomplishments of bombers.)

Hard on the heels of British Operational Research came the United States' Operations Analysis; and American names: Philip Morse, Ellis Johnson, Barton Leach, to list but a few. Stationed in England--where its commander could watch the goings on in the R.A.F.--the Eighth Air Force early asked for an operations research contingent. And by October 1942, General Arnold was dispatching a letter to all Air Force Commands "recommending that they include in their staffs operations analysis groups." 1/ What were their problems?

How best to use B-29's in mining operations? (Conclusion: single sorties; low altitude.)

Develop Techniques (search patterns) for hunting enemy ships and submarines.

In the face of kamikaze attack, should a ship maneuver violently, or keep straight ahead? (Conclusion: large ships should maneuver violently; small ships should change course slowly.) 2/

Question posed by a commanding general: "How can I put twice as many bombs on my targets?" 3/

1/ McCloskey, J. F. and Trefethan, F. N., Operations Research for Management, The Johns Hopkins Press, Baltimore (1954), p.13. For a short and readable treatment of operations research developed in England and the U. S., Florence Trefethan's chapter, "The History of Operations Research," is recommended reading.

2/ Ibid., pp. 16-18.

3/ Brothers, LeRoy A., "Operations Analysis in the United States Air Force," Journal of the Operations Research Society of America, Volume 2, No. 1, February 1954.

When the war was over the American Department of Defense instituted a project, called Research and Development, which took the acronym RAND, a project whose purpose was to consider the nature and effectiveness of weapons systems that might be prevalent in a future conflict between the United States and any potential enemy. One of the discoveries made by the researchers at Project RAND, was the fact that there was a very long lead time from the conception of the new weapons system until the time at which that weapons system would be fully operational and in quantity deployed in the hands of the troops. This observation led it to the conclusion that a weapons system whose quantity availability to armed forces would be some 15 or 20 years in the future, must be visualized as participating in a conflict where the enemy had also enjoyed the advantage of a 20-year development and procurement process. Accordingly, the RAND Corporation began to annex political scientists, behavioral scientists, and economists, for the purpose of visualizing the nature of the international conflict situation some 15 or 20 years hence. As is well known, this gave rise to strategic thinking of the sort that has become popularized in the writings of Herman Cahn in his book, On Thermonuclear War.

Futhermore, in speculating about the nature of future conflict in which the friendly side was regarded as behaving in a rational fashion, it was conceded that any potential enemy would also be regarded as behaving with similar motovations. Accordingly, it became important to make a forecast not only for ones self, but for any and all potential enemies and to estimate the expected consequences of any engagement in which the two combatants confronted each other with any pair of reasonable strategies. This led to the concept of describing an international conflict situation as if it were a two-person game. What remained to be done was to place a sensible number or value or expected result of the hostilities that would occur when the two combatants confronted each other with their own reasonable strategies. Although a wide variety of analytic approaches was attempted in pursuit of a sensible way of expressing the results of combat action, it was finally decided in desparation that the ancient military device of a sand table exercise or map maneuver should be employed as a vehicle for estimating the probable results of a conflict situation in which both sides behaved in a sensible way responding to the overt actions of his enemy as he sensed them. Thus the traditional war game was converted from a training exercise to one that was designed for diagnostic purposes so as to be able to better estimate the probable future consequences of given possible conflicts. Because it was necessary in theory to repeat the conflict under a rather wide variety of initial assumptions concerning force levels, type of weapons, degree of surprise, extent of communications, different tactical forms, etc., it became necessary to develop a rapid calculating sequence that would permit an umpire to deliver a judgment to each of the players concerning the rate of advance of their forces, the damage inflicted by each of the sides upon each other, and the remaining state of supplies in various categories. This grew into rather extensive umpire manuals to serve the hand played war game and an elaborate computer filled repetoire of performance characteristics for those games that were designed to be played exclusively on a high speed digital computer.

The year 1948 also saw the creation of an Army non-profit think factory called the Operations Research Office, which was conducted under a contract relationship between the Department of the Army and the Johns Hopkins University. This organization conducted research of a nature rather similar to that of the RAND Corporation, but for the United States Army. The early study of the Operations Research Office concentrated also on the expected battlefield performance of weapons systems and on the nature of psychological warfare. The outbreak of the Korean hostilities provided an opportunity once again to place operations researchers in a combat situation so that they might contribute significantly to the conduct of the war. In this case, the Operations Research Office sent approximately 100 of its analysts over a period of several years, to the Korean theater of operations, where they analyzed questions concerning the effectiveness of the armored forces, the procedures for improved close support bombing, and decoded the Chinese bugle calls. One of the more illustrious of the consultants to the Operations Research Office, General S.L.A. Marshall, in visiting the Korean battlefield, discovered that the expected combat effectiveness of the Ml rifle which was approximately quite high in proving ground operations had degraded significantly in the hands of the G.I. It furthermore developed that the performance of the soldier and the nature of his environment contributed far more to the effectiveness of the rifle than did marginal improvements in the firing technology of the rifle with which he was supplied.

The Operations Research Office interacted very vigorously with the development of the war gaming prodedures at the RAND Corp., with each organization complementing and improving upon the discoveries ot the other.

At the Operations Research Office there developed a strategy of research that insisted that along with every hardware and conceptual development there should be conducted a field test or experiment that would replicate, as nearly as possible, the active field conditions under which the new concept or weapon would be tested, and this came to be known as Operational Experimentation.

The Navy continued its WWII activities in operations research and established what came to be known as the Operations Evaluation Group. This organization became increasingly concerned with well-defined problems concerning performance of naval weapons, tactical maneuvers, and the logistics system in support of future combat operations.

The Joint Chiefs of Staff developed an operations research capability in its Weapons Systems Evaluation Group, the civilian component of which came to be known as the Weapons Systems Evaluation Division of the Institute for Defense Analysis (IDA). IDA also has several other organizations that operated in support of the civilian secretariat of the Department of Defense and concerned themselves with problems of an inter-service nature.

Finally, the Air Force developed what was known as Air Force Operations Analysis Office, which was characterized by a rather small central staff housed at the Pentagon, reporting at a very high level, but whose prime operations were concentrated in one or two man teams located at field installations and with somewhat larger groups at major command headquarters, such as the Air Defense Command in Colorado Springs. These people concerned themselves with problems of the sort that had characterized the WWII efforts in both the United Kingdom and American forces of solving problems on the spot of concern to the local commander, and whose purpose was the improvement of operations in the immediate future. These people became very adapt at developing field expedient techniques for estimating the consequences of new hardware or of new restrictions imposed upon the command.

The Air Force also assisted in the development of calculatiing procedures for what came to be known as the Simplex Method for the solution of problems of a linear programming nature. The project, known as SCOOP (Scientific Computation of Optimal Programs), was an attempt to estimate the requirements in terms of raw materials and personnel that would be placed upon the American economy as a consequence of the stipulation that a certain size defense force was required. The logic of the situation was that the requirement for a squadron of bombers would place a demand for aluminum, pilots, ton-miles of transportation, electrical equipment, etc. Each of these materials would levy a requirement on other men and materials. Steel is required in the production of aluminum, transportation in conveying the steel to the aluminum plant, etc. The net problem then, became one of calculating total raw material and personnel requirements to produce the defense force, and because of the substitutability of one material for another, it became possible to develop a statement of the problem in which one could reasonably ask the question, what is the least cost way of arriving at the hardware requirements that were levied against the system? Out of this program there emerged a long chain of researches into the computational procedures (computing algorithms) to permit one to arrive in an efficient manner at the determination of the least cost program and to be certain that having arrived at an answer, it was in fact, the least possible cost program.

Associated with the Defense non-profits, there grew up a rather significant in-house operations research capability at a number of defense installations to support problems of local concern.

The defense contractors who produced the hardware for the use of the defense establishments found it necessary to perform their own evaluations of possible solutions to military problems that would satisfy their own requirements for profitability, while at the same time satisfying the defense requirements for the fielding of a new piece of equipment. Accordingly, these industries, especially those in the aerospace community, developed a significant operations research, systems engineering cadre of people who were quite proficient at comparing the relative utility of an additional redundant circuit in a missile guidance system with increasing the life and the weight of existing circuitry. The Defense establishment therefore, had both the advantage and the disadvantage of receiving comparative evaluations of weapons systems and estimates of future combat situations from its in-house people, from its non-profit contractors, and from industrial manufacturers, who were seeking to provide the hardware required by their potential customers.

American industry also grew rapidly in its use of operations research immediately following WWII. It extended and applied the techniques of inventory control, of machine replacement policies, of calculating the proper mix of investment portfolios, and of estimating a preferred marketing strategy where the measures of worth could be calculated in terms of profitability, exposure to the market, share of the market, etc. American industry also discovered that the military war game could be retreaded for civilian purposes to create what came to be known as a management game. In such a situation, each of several competitive departments in a corporation was enjoined to improve its own performance and a corporate management normally in the form of an umpire and a market demand also normally in the form of an umpire, specified the operating conditions at the beginning of the next time frame. The purpose of the exercise was to discover ways to take advantage of the interacting effects of the marketing function, the production function, the research function, and the financial functions of a corporation so that the total profitability could be enhanced.

The universities in the meantime had begun to develop the notion that there was something teachable in the area of operations research, and promptly sought ways to render the content of such a curriculum explicit. The Johns Hopkins University, Case Institute of Technology, and Massachusetts Institute of Technology, introduced curricula that initially were based on the recitation of a series of case studies developed from the practitioners' register of completed and in-process studies. It became apparent, both to the university community and to the practitioners, that there was an underlying common thread to all of the reasoning that lay behind the solution of operations research problems. This common thread could be best described as a theory of "optimization." Optimization cast in simple language is the process of discovering how to achieve the maximum productivity or the maximum payoff from a set of fixed resources; the converse of the problem is to discover how to achieve a given level of performance or service with the expenditure of the lowest amount of resources. Each of the problems seemed to repeat the sequence, either maximize the performance or minimize the cost.

Whenever the sientific attitude addresses itself to a totally new problem area, it initiates its activities by attempting to discover the simplest possible underlying structure that will serve to explain the performance of the system in its grossest aspects, and then to proceed to correct the minor deficiencies in prediction by elaborating on the theory, or on the definition of the elementary particles assumed for the theory, or the description of the way in which they affect each other.

The existing procedures of mathematical optimization theory soon began to underpin the computational procedures that had been discovered to serve the important purpose of arriving at an optimum answer to a well structured problem. There soon arose an imperfectly integrated set of mathematical tools that seemed to fit a rather wide variety of recurring problems that had been described as operations research. These have been summarized in an eminently readable manager oriented book by Ackoff and Rivett, titled A Manager's Guide to Operations Research. 1/

1/ A Managers Guide to Operations Research by Ackoff and Rivett, P. 36

<u>Inventory Problems</u>. "Now an inventory problem can be defined as one in which at least one of each type of cost is involved and where the sum of these costs is affected by either the quantity of the resource acquired per order (e.g. production or purchase quantities), or the frequency of acquistion, or both. The problem, of course, is to select the quantity or frequency of acquisition, or both, so that the sum of the relevant costs is minimized."

<u>Allocation Problems</u>. 1/ "An allocation problem of the first type is defined by the following conditions: 1) There is a set of jobs (of any type) to be done. 2) Enough resources are available for doing all of these. 3) At least some of the jobs can be done in different ways and hence by using different amounts and combinations of resources. 4) Some of the ways of doing these jobs are better than others (e.g. are less costly or more profitable). 5) There are not enough resources available, however, to do each job in the best way."

<u>Queuing Problems</u>. Queuing problems are those in which a service facility provides a service process or transmits a message subject to fluctuating demands. The purpose of these problems is to estimate the total load on the system at any instant of time and to identify expected waiting times for the processing of service for any arriving customer.

<u>Sequencing Problems</u>. 2/ In queuing problems the order in which waiting customers are selected for service is usually assumed to be specified. Sequencing problems are concerned with selecting a queue discipline so that some appropriate measure of performance is minimized; for example, the total elapsed time required to service a specified group of waiting customers. This may have to be done under a system of priorities as, for example, when there are due-dates on production orders, and penalties for delay in delivery.

1/ A Managers Guide to Operations Research by Ackoff and Rivett, P. 38

2/ A Managers Guide to Operations Research by Ackoff and Rivett, P. 43

<u>Routing Problems</u>. 1/ Mathematicians have long amused themselves with very difficult problems which are treated like puzzels. One of the more recent of these is the 'traveling salesman problem.' It is usually formulated somewhat as follows. A salesman has a certain number of cities he must visit. He knows the distance (or time, or cost) of travel between every pair of cities. His problem is to select a route which starts at his home city, goes throught each city only once, and returns to his home city in the shortest possible distance (or time or cost).

<u>Replacement Problems</u>. 2/ Replacement problems are of two general types: Those involving items that degenerate with use or the passage of time, and those which do not, but which die or fail after a certain amount of use or time. Items that deteriorate are likely to be large and costly, for example, machine tools, trucks and ships, generators, and home appliances. Nondeteriorating items generally maintain a fairly level efficiency throughout their lives, but suddenly stop operating completely. These items tend to be small and relatively inexpensive; for example, light bulbs, vacuum tubes, tire tubes, automobile springs, rubber bands and ball-point pen fillers.

<u>Competitive Problems</u>. 3/ Now we consider a class of problems in which the decision taken by one decision maker is affected by the decisions made by one or more other decision makers. The relationship between the interacting decision makers may be either cooperative or competitive. As yet, unfortunately, there has been little analysis directed towards increasing the effectiveness of cooperation; but a great deal has been done to increase the effectiveness of competition.

<u>Search Problems</u>. 4/ In looking for something, there are two kinds of errors which can be made: 1) failure to detect what one is looking for because of inadequate coverage (sampling error), and 2) failure to

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1/ A Managers Guide to Operations Research by Ackoff and Rivett, P. 46

2/ A Managers Guide to Operations Research by Ackoff and Rivett, P. 47

3/ A Managers Guide to Operations Research by Ackoff and Rivett, P. 50

4/ A Managers Guide to Operations Research by Ackoff and Rivett, P. 53 and 54 detect what one is looking for even though one has looked in the right place, or erroneous 'detection' of the thing which is not there (observational errors). There are, of course, costs associated with both types of error and with the collection of information. If one has a fixed amount of resources (time, money, or searchers) a decision must be made as to how much coverage to have (sample size) and what type (sample design). The larger the sample the less is the likelihood of sampling error, but the less time spent per observation, the more likely is an observational error to occur. The selection of an appropriate sample size and design with fixed resources is the restricted search problem. In the unrestricted version of this type of problem one must also decide how much resources to use in the process. The more resources employed, the greater is the cost of the search but less is the expected cost of error.

Among the interesting discoveries that was made was that it became possible to cross step from one technique to another. For instance, it was discovered that for every zero sum two-person game, it became possible to specify an exactly equivalent linear programming problem. It also bqcame possible to interchange certain types of queuing theory formulations for an inventory problem. The operations research theoreticians are searching vigorously for the best expression of the mathematical form that is common to all the procedures that underline these various calculations. The bulk of this research is conducted in universities, but with some of it being conducted in the basic research establishments of the Department of Defense non-profit corporations.

At the present time, approximately fourteen universities in the United States offer graduate degrees with majors in operations research. The Johns Hopkins University, one of the earliest in the field, continues to be a leader in this regard. Case Institute of Technology, Carnegie Institute of Technology, Massachusetts Institute of Technology, The University of California (Berkeley), Northwestern University, New York University, Stanford University, the United States Naval Postgraduate School, Cornell University, the University of California at Los Angeles, the University of Michigan, the University of North Carolina, the University of Pennsylvania, have relatively well-developed programs in operations research. Other universities are actively building departments and offer degrees with partial specialization in operations research as a strong supporting area. The University of Maryland belongs in the latter category, but like several other Washington metropolitan area universities, is engaged in a very active program of expansion in this area.

The curriculum of these universities is rather heavily oriented in the mathematical direction, but the large proportion of graduate student support comes from the conduct under the guidance of a professor of sponsored research projects for various outside agencies. The use and encouragement of problem-solving by university graduate students is one of the relatively untapped low cost sources of problem solution that would be available to the State of Maryland in carrying out its program of operations research. A still greater untapped source of assistance to the State is the subsidy of laboratory problems to be used by an instructor with his complete class with a full semester seminar problem-solving activity being perhaps at the upper end of the spectrum of what is possible.

About a decade after the completion of WWII, a rather vocal fraction of the operations research fraternity began to make rather pointed suggestions that the Federal Government should be considering the sponsorship of operations research to the problems of the non-defense agencies of the Federal Government.

The Department of Agriculture discovered rather early in its history that it was possible to adapt the linear programming scheme of calculations to the determination of a least cost feed mixture to give to livestock. This in turn had significant appeal in the field activities and extension services of the Department of Agriculture in its efforts to assist the American farmer.

The Post Office Department began to calculate the characteristics that would be required of a mechanical mail handling machine that would transact the sorting operations in minimum time or at a minimum cost, and to determine where to locate a new post office in a developing population area so as to provide the best possible service to the clientele.

The Federal Aviation Agency began to concern itself with problems related to the congestion of the runways at airports and the calculation of criteria to determine when an expansion of the capital investment in airport and air traffic control facilities should be introduced.

The Social Security Administration was among the first to conduct an extensive feasibility study for the application of the techniques of operations research to the total operations of the administration and settled upon studies related to the best use of the nationwide automated computing facilities that serve the administration, and to the questions of the staffing of field and district offices.

One of the very significant confluences of tradition occurred when the operations research analysts and the mathematical economists began to notice that each was solving problems that had customarily been regarded as being primarily within the domain of the other discipline. There were two areas in which rather sensational progress was achieved with respect to the marriage of these two traditions. The first of these was at the RAND Corporation in which questions relating to the costing of a weapons system that had not yet been developed arose and in the development of a calculus that would permit one to compare weapons systems with widely variant cost and effectiveness characteristics. The procedures for this kind of analysis came to be known as cost effectiveness analysis. The second major confluence of mathematical economics and operations research has begun to take place as a result of the exposure of the operations research analysts to the benefit-cost calculating precedures developed by the Department of the Interior, Harvard University, the Corps of Engineers and other organizations concerning the question of what costs and benefits are properly includable when one considers alternate plans for the management of the river basin. The more recent publication of the book concerning the Economics of Defense in a Nuclear Age, by Charles K. Hitch and an earlier volume by Roland McKean, titled Efficiency in Government Through Systems Analysis provided the structural basis for the introduction of the cost-effectiveness calculations that have been institutionalized in the Department of Defense.

One of the discoveries of the non-profits was that it became relatively difficult, if not impossivle, to forecast the lifetime costs of a weapons system based on the traditional accounting categories. It was normally possible, for instance, to estimate the research and development costs associated with the weapons system and it was possible to provide expansion factors to reflect the fact that initial estimates of total cost were invariably modest by a factor of from two to ten. It also became possible to estimate major item procurement costs, depending upon the quantity ordered, but correspondingly difficult to estimate the procurement costs for the equipment that was associated with the prime weapons system being introduced. It was multiply difficult to determine the lifetime maintenance costs on these pieces of equipment whether they were end item or whether they were associated equipment. Considerations relating to the costing of repair parts procurement, modification work orders, and the operations of the supporting supply system, to say nothing of the informal operations, that add life and richness to the supply system were all difficult. Accordingly, the notion was developed that the proper way to provide the information that would make a decision concerning the introduction of a new weapons system a rational one, would be to assemble in one package all of the costs that were relevant to and implied by the introduction of the new weapons system. Because of the mutually supporting characteristics of many weapons--tanks, infantry and artillery, for instance--it was agreed that the packages should be assembled in terms of functional programs so as more properly to reflect the interacting nature of the components of the military campaign.

More recently, the United States Department of the Bureau of the Budget has required 21 of the agencies of government to institute an analagous system of budget documentation, known as the Planning Programming and Budgeting System. In the search for improved management of the individual agencies of government, the intention of course, is to expand the concept to all executive branch agencies, not just the initial 21.

The growth of operations research in the non-defense agencies of the Federal Government has enjoyed a new rebirth. It is now in an exponential era of growth, but is suffering from a delay time of approximately a decade or a decade and a half behind the developments in the defense and industrial communities. It is probably fair to say that none of the non-defense agencies of government is staffed for a systems analysis or operations research program at a level that properly reflects the depth and content of the problems of that agency by almost any measure of level of effort. It is apparent that between 85 and 90% of the operations research community is working on defense, space, or industrial problems, with the remaining rather small fraction concerning themselves with problems related to the common welfare and to the non-defense activities of our nation.

Now within the non-defense sector of government, it becomes evident that one can, in fact, apply a number of the more or less traditional techniques of operations research in the narrow sense of the word, with reasonable expectation of discovering rather significant improvement either in the performance of an operation or in the realization of cost reductions in carrying it out. The expectation is substantially similar to the experience that was encountered in early days in the Department of Defense and in American industry. Hence it would presumably be a matter of expectation that the total cost of inventory activities in support of an operation might be reduced by something like five or ten percent with respect to the price of the service, and that measures of the availability of supply would introduce an improved across the board balanced availability of parts when needed. The same could be expected to be true with respect to the use of linear programming techniques for producing a least cost or minimum route scheduling of school buses. In most of these rather restricted cases, the next steps that are necessary are rather apparent, and indeed rather significant inroads have been made to initiate their use in the non-defense agencies of government. The General Services Administration for instance, normally applies an economic order quantity calculating procedure for the provision of the proper stocking levels of federal supply items. The Department of Agriculture conducts studies related to the computer blending of warehouse grain receipts. The Office of Business Economics in the Department of Commerce employs an 86 sector input-output matrix to represent the operations of the United States economy. The Office of Education is constructing a mathematical model to relate resource allocations in federal activities in support of the educational process with the level of educational achievement experienced by the American citizen.

What also seems apparent is that it is possible to apply operations research or systems analysis in the very broadest sense of the word in an attempt to structure problems that appear to be basically unstructured insofar as an ability to describe a decision problem rationally is concerned. The recognition of the opportunities for carrying out an effective examination of major problems that confront American society has prompted the introduction of a number of bills into the 89th Congress recommending the establishment of a mechanism to mobilize the systems analysis communtiy to study these urgent problems. The proposition advanced in these bills is that systems analysis and systems engineering approaches should be adopted to problems in the area of education, unemployment, welfare, crime, juvenile delinquency, air pollution, housing, transportation, and waste disposal. Earlier resolutions reached in the Congress include Senate Joint Resolution 202 from the 88th Congress, matched by House Joint Resolution 666 in the 89th Congress, proposing the establishment of a Presidential Advisory Staff on Scientific Information Management whose purpose would be to assure the effective focusing of both the operations research and information processing communities on urgent national problems. More recently, a bill was introduced simultaneously into the Senate and House of Representatives to create a commission to analyze the possible application to public programs of the techniques of operations research, econometrics, mathematical programming and modeling, simulation, project management, and the use of automatic data processing devices and procedures for program control and information systems. Among the significant non-defense problems described in the presentation of the bill, were those of air polution, the availability of pure water, the substandard condition of much of the nation's housing, the existence of traffic jams, and the explosive doubling rate of modern scientific and technological information.

In nearly all cases, it becomes apparent that these problems have considerable appeal and that the extension of the systems analysis techniques to the problem areas are likely to produce significant payofffs, but that there are some outstanding procedural and factual problems that must be resolved if the application of systems analysis in these areas is to enjoy the success which the initial promise suggests is within reach. Among the most frequently mentioned problem that permeates the non-defense area of research, is the difficulty of identifying a suitable measure of effectiveness of public service programs, although economists have generated the notion of a social welfare function to reflect the inclusion of all kinds of utilities or benefits to be derived from public programs, it is not completely clear that all of the ingredient parts of a social utility function are quantifiable. Furthermore, the mere presumption that a social utility function should be maximized immediately invokes the question of how best to introduce the distributive effects of benefits in such a way as to reflect inbalances among socio-economic groups. Finally, it introduces the complication that all measures of benefit must be at least representable by some number that transforms each of the ingredient parts of the worth measure to a common denominator.

The Operations Research community, therefore, is being pressed to carry out analyses for which the capital investment in understanding the nature of the problems has not yet been made. Within the defense establishment, it is possible to count in the thousands the number of analysts who can be regarded as having had several years of experience in military operations research and it is possible to count in the hundreds, those whose experience has spanned nearly a decade. There is a large established institutional memory bank in the form of the non-profit organization and in the digested understanding of the results of military operation research studies in the minds of the users of those studies.

No such well developed base exists for the non-defense agencies of government. There is a requirement to make an investment in method development, to say nothing of obtaining the factual experience.

The Legislative propositions followed quickly on the heels of what has come to be celbrated as "the California studies." Governor Brown of the State of California, late in 1964, asked the aerospace firms in his state to recommend approaches taken from the system analysis tradition to the resolution of problems in transportation, waste, crime, and the creation of a state-wide information system. A clear text summary and evaluation of this California experiment is provided in Appendix Volume 5, "Applying Technology to Unmet Needs" to the report of the National Commission on Technology, Automation, and Economic Progress. In the case at hand, the state government decided that it would provide $100,000 for each of four studies to be carried out over a six-month period and to be funded exclusively from the Budget of the California legislature. Each of the firms who contributed their skills to the study of these problems probably spent well in excess of the funded income designated for the conduct of the studies. Some of the unsuccessful bidders on the research contracts are reported in the Commission's appendix as having expended up to $150,000 in the preparation of the proposal.

The general results of the six month's studies was the creation in each of the four areas of a proposed master plan for the creation of:

1) A California state-wide information system to be developed over a ten year period at a total cost of a hundred million dollars over the decade and with an annual operating cost at the end of the period of approximately 13 and a half million dollars.

2) The generation of a large volume of information concerning the nature of the waste materials generated in the state, and in the development of some preliminary mathematical models of waste handling techniques, a socio-economic projection and a procedure for evaluating technological alternatives to the improvement of the effectiveness of the waste management program with a three year program of study to be initiated.

3) A preliminary mathematical model of the operation of the system of criminal detection, apprehension and administration of justice with cost effectiveness measures associated with it and the proposition that a continuing program of systems engineering, as well as direct operating programs to reduce the effects of crime, at a cumulative 5-year cost of 120 million dollars.

4) An extensive plan of research and analysis over a 4½ year period at a cost of 6 to 9 million dollars of a system of land use, population, economic, transportation, and evaluation models, to be fully integrated and provide a means of assessing transportation needs and comparing possible resolutions of the problems in the future.

The California experiment attracted considerable attention for a variety of reasons. It illustrated the willingness and desire of the aerospace industry to address questions of concern to the civilian sector of the economy. It was a significant frontal assault in the identification of what would happen if someone applied the systems analysis techniques to rather broad gauge problems. It illustrated some of the difficulties that would be consequent upon adopting an impartial mode of operation in a tradition that had been developed over a long number of years.

The California studies illustrate one important characteristic of systems analysis when conducted on major problems, and this is that for purposes of completeness of the study and for total relevance, a natural end product is to expect the installation of a rather comprehensive management scheme, which may be limited solely to providing information and assembling it in interesting ways for comparing alternatives, or it may extend more ambitiously into the area of what in the defense establishment would correspond to an on-line real time management information system.

Reference to revenue and expenditure summaries of the states for fiscal year 1965, illustrated in Table 1,1/would suggest that extensive management information systems may prove to be a burden beyond the financial capabilities of a number of states to introduce, in a very widespread fashion. Indeed, there would appear to be some merit in raising the question with the Council of State Governments as to whether it would be possible to assure through joint action, that all states could receive the benefits and perhaps share in the costs, of the creation of systems that would have strong interstate analogies.

1/ Compendium of State Government Finances in 1965, U. S. Department of Commerce, Bureau of the Census.

Table 1.--NATIONAL SUMMARY OF STATE FINANCES: 1963 TO 1965--Continued

Item	Amount, in millions			Percent increase or decrease (-)		Percent distribution, 1965	Per capita, 1965[1]
	1965	1964	1963	1964 to 1965	1963 to 1964		
EXPENDITURE, BY FUNCTION--Continued							
Liquor stores expenditure	$1,022	$977	$900	4.6	8.5	(X)	$5.30
Insurance trust expenditure	4,170	4,364	4,306	-4.4	1.3	100.0	21.61
Employee retirement	1,238	1,125	995	10.1	13.1	29.7	6.42
Unemployment compensation	2,288	2,627	2,750	-12.9	-4.5	54.9	11.85
Workmen's compensation	394	374	360	5.4	3.9	9.5	2.04
Other	250	238	202	4.9	18.0	6.0	1.29
INDEBTEDNESS AND DEBT TRANSACTIONS							
Debt at end of fiscal year	27,034	25,041	23,176	8.0	8.1	100.0	140.06
Long-term	26,235	24,401	22,751	7.5	7.2	97.0	135.92
Full faith and credit	11,819	11,147	10,658	6.0	4.6	43.7	61.23
Nonguaranteed	14,415	13,254	12,093	8.8	9.6	53.3	74.68
Short-term	800	641	424	24.9	51.1	3.0	4.14
Net long-term debt at end of fiscal year	22,504	20,922	19,480	7.6	7.4	(X)	116.59
Full faith and credit only	9,094	8,434	7,988	7.8	5.8	(X)	47.11
Long-term debt at end of fiscal year, by function:							
Total	26,235	24,401	22,751	7.5	7.2	100.0	135.92
State institutions of higher education	3,556	2,886	2,450	23.2	17.8	13.6	18.42
Local schools	2,410	2,122	1,957	13.6	8.4	9.2	12.49
Other education	480	234	229	105.4	2.2	1.8	2.49
Toll highway facilities	6,241	6,313	6,043	-1.1	4.5	23.8	32.33
Other highway facilities	4,037	3,952	3,850	2.1	2.7	15.4	20.91
Hospitals	216	238	255	-9.0	-6.8	0.8	1.12
Water transport and terminals	322	327	342	-1.6	-4.2	1.2	1.67
Veterans' bonuses	624	718	813	-13.2	-11.7	2.4	3.23
Other and unallocable	8,348	7,611	6,813	9.7	11.7	31.8	43.25
Long-term debt issued	3,022	2,793	2,103	8.2	32.8	100.0	15.66
Original issues	2,769	2,489	1,982	11.3	25.6	91.6	14.35
Full faith and credit	1,257	1,118	952	12.4	17.4	41.6	6.51
Nonguaranteed	1,512	1,370	1,029	10.3	33.1	50.0	7.83
Refunding issues	253	304	122	-16.7	150.2	8.4	1.31
Long-term debt retired	1,230	1,188	1,014	3.6	17.1	100.0	6.37
Redeemed	1,082	1,002	930	7.9	7.8	87.9	5.60
Refunded	149	185	84	-19.7	120.1	12.1	.77
Borrowing	2,957	2,717	2,032	8.8	33.7	(X)	15.32
Debt redemption	1,130	1,036	976	9.1	6.2	(X)	5.86
CASH AND SECURITY HOLDINGS							
Total	51,329	45,862	41,379	11.9	10.8	100.0	265.93
Cash and deposits, unemployment compensation systems	7,426	6,580	6,017	12.9	9.4	14.5	38.47
Other cash and deposits	6,416	5,572	5,000	15.1	11.5	12.5	33.24
Securities	37,487	33,710	30,362	11.2	11.0	73.0	194.21
Federal securities	13,963	13,283	12,362	5.1	7.5	27.2	72.34
State and local government securities	2,398	2,630	2,987	-8.9	-12.0	4.7	12.42
Other securities	21,126	17,797	15,013	18.7	18.5	41.2	109.45
Cash and security holdings of insurance trust systems	31,379	28,058	25,174	11.8	11.5	61.1	162.57
Employee retirement	22,093	19,726	17,465	12.0	12.9	43.0	114.46
Unemployment compensation	7,426	6,580	6,017	12.9	9.4	14.5	38.47
Workmen's compensation	1,716	1,598	1,498	7.4	6.7	3.3	8.89
Other insurance trust systems	145	154	194	-6.4	-20.5	0.3	.75
Cash and security holdings, other than insurance trust systems	19,950	17,804	16,205	12.1	9.9	38.9	103.36
By purpose of holding:							
Offsets to long-term debt	3,730	3,479	3,272	7.2	6.3	7.3	19.33
Bond funds	2,201	1,837	1,865	398	-1.5	4.3	11.40
Other	14,018	12,488	11,069	12.3	12.8	27.3	72.63
By type of asset:							
Cash and deposits	6,197	5,376	(NA)	15.3	(NA)	12.1	32.11
Securities	13,752	12,428	(NA)	10.7	(NA)	26.8	71.25
Federal Government securities	7,523	7,222	(NA)	4.2	(NA)	14.7	38.98
State and local government securities	1,327	1,364	(NA)	-2.7	(NA)	2.6	6.88
Other securities	4,902	3,842	(NA)	27.6	(NA)	9.5	25.40

Note: Because of rounding, detail may not add to totals. Per capita and percent figures are computed on the basis of amounts rounded to the nearest thousand. X Not applicable. NA Not available. [1]Based on estimated population on July 1, 1965. [2]Less than 0.05 percent. [3]Revised. [4]Rents and royalties included in "Other" in 1963.

Summary 1/

Table 3.--SUMMARY FINANCIAL AGGREGATES: 1965

(Millions of dollars)

State	Total	Borrowing	Total
All States	48,827	2,957	45,507
Alabama	809,438	81,303	781,328
Alaska	191,073	33,131	202,222
Arizona	468,235	12,801	439,967
Arkansas	392,781	7,166	368,229
California	6,216,449	576,696	6,122,871
Colorado	542,964	5,808	523,849
Connecticut	674,445	91,900	655,374
Delaware	190,716	40,904	190,955
Florida	1,197,156	123,763	1,145,196
Georgia	905,790	107,935	819,084
Hawaii	287,256	41,235	273,306
Idaho	196,195	3,625	182,239
Illinois	2,116,048	53,515	2,066,010
Indiana	1,066,367	25,629	1,006,440
Iowa	660,390	12,712	637,774
Kansas	475,796	13,720	453,123
Kentucky	689,385	16,850	690,359
Louisiana	1,124,135	50,194	1,079,671
Maine	251,721	193	227,398
Maryland	852,286	71,650	787,535
Massachusetts	1,223,536	224,372	1,273,120
Michigan	2,419,986	43,685	2,053,768
Minnesota	936,125	17,400	890,697
Mississippi	486,176	31,113	469,079
Missouri	902,515	3,425	819,843
Montana	228,289	10,507	221,567
Nebraska	242,298	3,545	237,538
Nevada	178,467	3,515	166,981
New Hampshire	160,897	13,150	154,837
New Jersey	1,192,873	54,633	1,060,882

1/ Compendium of State Government Finances in 1965
U. S. Department of Commerce
Bureau of Census

State	Total	Borrowing	Total
New Mexico	390,643	27,412	353,778
New York	4,948,658	389,655	4,600,888
North Carolina	1,086,443	3,443	939,605
North Dakota	209,015	3,792	199,265
Ohio	2,408,951	165,235	2,016,961
Oklahoma	672,649	17,430	679,712
Oregon	686,757	44,170	623,788
Pennsylvania	2,941,696	189,231	2,559,301
Rhode Island	240,447	45,650	237,005
South Carolina	502,285	21,242	457,275
South Dakota	168,693	4,565	172,047
Tennessee	751,947	27,144	702,747
Texas	2,149,901	39,487	1,793,112
Utah	325,434	8,035	338,704
Vermont	142,537	15,090	135,006
Virginia	997,788	23,415	929,684
Washington	1,159,188	39,257	1,100,590
West Virginia	482,610	65,180	465,743
Wisconsin	1,119,396	49,362	1,048,727
Wyoming	162,095	1,860	152,100

The Council of State Governments, is, of course, exploring the questions of automatic data processing equipment and management information systems; it is entirely possible that some of the major efforts to create large-scale systems analysis schemes might be more profitably developed under the aegis of an interstate compact than by any single state individually.

The California studies appear to have suffered from yet one other defect which has come to be recognized as one to be avoided in the defense and industrial communities. This defect is that unless there is a receiving agent who can understand the study and place it in proper operating perspective of the receiving agency, much of the research investment will have been lost or its utility seriously postponed. Accordingly, it becomes important in laying out any program of operations research for the State of Maryland to assure that a receiving mechanism is in place in the executive branch of the state government to guarantee that the fruits of the research are employed to the greatest possible advantage.

Projections of state and local government spending over the decade or two immediately ahead suggest that such expenditures will probably double in the next decade and might perhaps expand at a still faster rate. The primary elements of growth estimated by the forecasters lie in the fields of transportation and education. It is, of course, expected that a fair proportion of this revenue will come directly from the Federal government. Although other areas of expenditure by state and local governments for health, pollution control, the management of natural resources, and the provision of police services are expected to double also, the relatively low comparative investment at state and local levels make their total contribution to the projected growth a rather modest proportion of the total expenses.

Within the United Kingdom, yet another development has taken place. Over the last half dozen years, the Royal Institute of Public Administration and the Department of Scientific and Industrial Research has been sponsoring relatively small studies of operational research techniques as they might be applied to a variety of the support services provided by local and county administrations in the United Kingdom. Such items as the scheduling of transport and the replacement of lorries have suggested to local administrators that there is considerable advantage to be gained through the incorporation of operations research techniques into the management of local organizations. Following on some of these earlier studies the proposition was advanced by the Royal Institute of Public Administration to the 62 counties and 84 boroughs (towns) of England and Wales that they voluntarily contribute small sums of money proportional to their income or population to create a small local operational research unit. Approximately 50% of each of the jurisdictions approached agreed to provide a donation for each of five successive years. In 1967, the expected revenue to this now created Local Government Operational Research Unit1/ amounts to 40,000 pounds sterling in donations from the government units, supplemented by 30,000 pounds sterling in reimbursable study contracts. The Local Government Operations Research Unit has requested the central government of the United Kingdom to provide a further subsidy of 20,000 pounds. This group, now numbering approximately 22 sciehtists, with a supporting clerical and administrative staff of 10, has concentrated on small one and two-man studies of relatively short duration involving problems of the following nature:

1) A study of the split of expected transportation demand among modes of travel comparing the expected usage of private automobiles with public bus transportation. This, of course, is similar to the types of studies now donducted in comparing the estimated desirability of the introduction of a mass transit system in a major metropolitan area.

2) The generation of a forecast of the expected school population to be reinterpreted in terms of the demand for educational facilities especially in view of the rapidly developing nature of some of the previously suburban areas in England. The work which originated in Hertfordshire and which was based on a computer formula for forecasting school-age populations for both public and parochial schools has subsequently been expanded to the new town development corporations and the Scottish Education Department.

3) A recently instituted study has been the development of a forecasting model to estimate the nature of educational and social services that can be expected to mature 20 to 30 years after the creation of a new town.

4) One of the prime areas of multiple project activities has been associated with a series of studies vectored toward improving lower cost and higher performance refuse collection for towns. In these cases, refuse collection programs developed the information that it was possible for towns jointly to use disposal locations to the net economic advantage of both participating institutions. Preliminary examination has been made to discover whether additional gains would accrue from the use of regional area refuse disposal sites by as many as 19 townships associated with a river basin.

1/ 199 King's Road, Reading, England.

5) Calculations concerning the time of best (low cost) replacement schedules for garbage trucks and the determination of which type and size to procure has also been instituted and is nearing completion.

6) Studies directed at discovering the cause of high labor turnover rates for low paying tasks unearthed the observation that garbage collection teams who worked in parcels of three men tended to select a leader of the team, and that teams of individuals so created seemed to provide the cadre of a long-lasting work force, and they experienced far lower turnover rated than when workers were assigned to an arbitrary and changeable schedule.

7) In common with many industrial applications, a number of studies related to procurement policies with respect to supplies for schools and for stores that were used as warehouses for county and town purposes were made. In most of these cases, it was discovered that people were, in fact, behaving according to an uneconomic ordering procedure especially in school houses where a year's worth of supply was ordered to arrive at the beginning of the school term. Overcrowding of warehouses was subjected to an unnecessary seasonal surge, and deliveries arrived at a time that further congested the ability of the administrative structure to respond to it.

Associated with these studies was one that permitted the creation of a set of tables that could be used by any procurement clerk to indicate the discount prices that he should ask of a particular supplier in order to provide the least cost total inventory for his operation, and would conversely indicate to him whether or not the provision of a quantity discount offered by a supplier represented a net return that would offset the disadvantage of the additional storage costs of having an oversupply of equipment.

8) Also, in common with industrial inventory control studies conducted on both sides of the Atlantic, was one to determine whether it was more economical to have a central distribution point for major appliances that were delivered from a warehouse or whether it was better to have a relatively large number (in this case 26) district delivery locations from which all trucking could be accomplished on a local basis and with relatively small trucks. The study which was conducted for the Southeast Electricity Board by two analysts for a time period of 18 months, discovered that it was more advantageous both from a cost and quick delivery performance point of view to introduce 26 redistribution points for local delivery of supplies to a net advantage from a financial savings point of view of 160,000 pounds sterling per year. The salary and overhead rates for operations research analysts in this particular case yielded a net annual saving of approximately five to ten times the one time cost for performing the study by the OR analysts.

9) Still another study was made on the question of the extent to which the checking of invoices and purchase orders for accuracy would need to be performed, assuming for the time being that any legal impediments to performing a check on multiple occasions could be legislatively modified. The question was tackled as to whether or not it was necessary to check each invoice four times as had been the practice in the past. The first of these checks was made to assure that the appropriation permission had been granted to the agency to issue the purchase order. The second check was made to assure that the delivery of the materials matched the invoice declaration. The third check was made by the budget office to assure that the price quotations were accurate and as originally agreed upon, and the fourth check was a complete recapitulation for arithmetic errors. In practice, it was discovered that a complete check of each invoice did in fact occur in most cases at each of the four checking locations. It was a characteristic of this inventory system, as it is of most, that the largest volume of purchase orders were for relatively small sums. The proposition was therefore advanced that a selected sample of small purchase price invoices should be checked completely, but that a very large fraction should be bypassed and checked only once for authority to purchase and once for delivery.

The expected savings on approximately 180,000 invoices led to an estimate that if only the 12% of the highest valued invoices would be fully checked and a randomly selected 5% of all others were checked, one could expect to lose approximately 800 pounds sterling a year due to errors and avoidance devices, but that approximately 6,000 pounds would be saved in a year in clerical cost, for a net expected reduction of an operating budget of slightly over 5,000 pounds per year.

The system was instituted in the supply department of a major English city and the first year of operation suggested that the savings were real and that there was a relatively small amount of deceptive action undertaken by suppliers. The neighboring council noticing the reduced volume of expenditures for checking of invoices proposed a consolidation of its own invoice checking staff with that of the earlier organization and subsequently discovered that it was possible to handle the workload of both jurisdictions with the number of employees that had been previously employed by only one of the organizations. Needless to say, the system thus instituted has been subjected to continuing scrutiny to assure that in fact, these anticipated savings continued to be realized and to assure that control over the integrity of the checking system is a matter of fact.

A selection of these studies is reported in a readable paperback, authored by Raymond A. Ward, the leader of the group and titled, Operational Research in Local Government.1/

1/ Published by George Allen and Unwin Ltd. of London, 1964.

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organization in the early stages of the operations research activity such aontributions have tended to be in areas where mechanical functions are performed or in those systems where human and group involvements can be treated as if they were moderately mechanical in nature. Only after approximately five years of exposure to the facts, traditions, procedures, agreements, and folklore of a subject matter area has been experienced by the opertions research analyst does he in fact begin to contribute significantly to the advancement of the major interests of the organization he is supporting in a way that does not unknowingly destroy some of the built-in regulating and compensating mechanisms generated out of a long history of painful and expensive discovery.

III. OR IN THE NARROW

The recommendations concerning the program in operations research that would be of greatest possible use to the State of Maryland is broken down in this report into two major sections. The first of these relates to the use of operations research in the narrow sense of the word, and the second relates to operations research and systems analysis in the very broad sense of the word.

Operations research in the narrow sense of the word relates to the application of time tested methods for the improvement of operations in which it is reasonable to expect that moderately noticeable improvements in the cost of conducting an operation or in its performance can be expected if that operation is regarded as basically mechanical in nature.

The point of view adopted in this report is to attempt to take one step beyond the traditional array of potential uses of operations research techniques to situations that are regarded in the abstract as being possible areas where future payoffs might be expected. Instead, the point of view is taken that one should begin with an improvement in the currently applied calculating procedures and build upon them.

If one were to enumerate areas of potential application of techniques related to operations research in the State of Maryland, one would first identify those areas of relatively large expenditure from the state budget and relate them to prior experience where past applications of known techniques have led to some improvements. If one were to do this, with the budget of the State of Maryland, one would emerge with the following list of probable areas of research payoff.

1) Develop a set of revenue estimating models to include consideration of the elasticity of revenue generation due to changes in tax policy, and to the population and corporate base in the State of Maryland.

2) Construct a schedule of estimated expenditures for all state programs to extend over at least a five year period, and in the case of replacement of capital public investments over a time horizon sufficiently long to anticipate the need for their replacement. In the case of sewer systems, for instance, this might be a 50 or 70-year time horizon.

3) Indentify a list of potential opportunities for inputs of Federal funds into the State. In anticipating the creation of new or enlarged federal programs, estimate the impoovements believed to be of greatest significance to the growth of the State and which probably would not be undertaken unless Federal funds were available.

4) Identify opportunities for the combination of services that are common to several offices, institutions, (hospitals and schools) in which economies of scale might be achieved through the sharing of common functions.

5) Develop inventory models and warehousing models to provide for the least cost provisioning of supplies required for the public activities of the State.

6) Develop least cost schedules for the maintenance of state buildings. Alternatively, identify the optimal building maintenance schedule that would preserve a desired level of performance or service of each of the buildings.

7) Provide improved driver examination and licensing sequences in such a way as to identify possibly dangerous drivers on the basis of the characteristics of previously tested drivers who had proved to be poor accident risks.

8) Develop a scheme that would provide the maximum military readiness for the reserve troops of the state in case of mobilization.

9) Maximize the Civil Defense readiness of the State of Maryland in the sense that the greatest number of people would have fallout shelter protection, would have access to supplies, would have the greatest amount of emergency fire fighting and rescue equipment, or would have the greatest number of lanes of open highway in the event of a military emergency; develop simultaneously the best scheme for readiness to combat natural emergencies such as hurricanes, floods, and unexpected snow storms.

10) Provide an optimal patrol sequence for the State Police so as to give the greatest coverage of high danger zones and to provide the greatest amount of random searching and surveillance of the remainder of the state. Develop a procedure to identify an optimal automotive and vehicular maintenance and replacement schedule.

11) Determine whether improvements of a major order are possible in some of the more routine clerical tasks associated with the examining and licensing processes of the State Examining Boards.

12) Develop a least cost upkeep schedule for race tracks.

13) Determine a preferred highway construction plan, including the joint effects of state and county roads, along with the interstate highway system so as to provide the maximum throughput capacity for travelers in terms of their origins and destinations and travel patterns.

14) Determine an optimal (least cost or maximum performance) procedure for providing for the maintenance of highways for which the state and county have the responsibility for upkeep. Determine how many maintenance garages are required. Determine the least cost or a minimum time sequence for the maintenance of state highways, for the removal of snow so as to provide for the greatest volume of traffic being delivered from origin to intended destination and to provide for the greatest amount (mileage) of open highways in a major snowfall.

15) Estimate over a long time period (approximately 50 years) the quality and quantity of water in the river basins and the Chesapeake Bay, estimating the probable pollution introduced and to the extent possible, the ecology of the Bay, the rivers, and the surrounding watersheds.

16) Determine each year a modified hunting season for game so as to preserve a necessary population of animals to permit maintenance of wild life in the State.

17) Determine the number of fire lanes required in a forest for control of forest fires; the determination of the number of observation stations required and a manning schedule that would be responsive to conditions of dryness in the forests.

18) Determine the number of personnel required to operate the State parks and estimate the extent to which patronage of State park facilities by citizens of the State and visitors from our surrounding States would use the park, depending upon opportunities provided for them. Estimate, in view of expected population expansion, the location and amount of land that should be procured to assure adequate open spaces and recreational facilities for the use of state citizens. Identify those natural resources characteristics of the State of Maryland (Chesapeake Bay, mountains and ocean) for elements of uniqueness, and assure through zoning regulations and through willingness to release land to industries and the federal government the number of acres and location that are consistent with state development schemes.

19) Determine the extent of local health service provided to the citizens of the state; estimate the number of physicians required and determine the best location for the provision of health services.

20) Estimate the long-term needs of medical care programs in the State of Maryland.

21) Provide a means for estimating the number of out-patient cases and in-patient bed requirements for hospital patients in state hospitals over future years. Determine the extent to which common services (supply systems, laundries, etc.) can provide reduced operating costs for hospitals under control of the State.

22) As a function of other activities in the State of Maryland concerning economic development and the introduction of federal programs for individual and community improvement, estimate the extent and cost of welfare programs under state and local administration. Attempt to identify ways in which welfare payments could be superseded by the creation of job producing opportunities that would be appealing to the disadvantaged workers of the state. Provide an information system that would keep the state constantly informed concerning existing and forecasted unemployment levels by location and type of person.

23) Develop a scale for determining the priorities of various State programs that are postponable in times of fund shortages, and conversely, a priority scale for achieving those investments that become possible within the constraints placed on legislative appropriations to improve the starting condition of State programs at the initiation of the next fiscal year.

24) Develop improved and lower cost inventory operations for the custodial care at correctional institutions. Estimate the extent to which one can identify the rehabilitation of persons committed to correctional institutions.

25) Develop a procedure that would permit the estimation of the expected level of educational training that could be achieved as a result of comparing investments in new school buildings, textbooks, teachers, and other educational programs. Provide a means for estimating the rate of reimbursement of professionals in the educational system of the state that would maintain and enhance the notoriously high quality education on a secondary level in the State of Maryland.

26) Determine the number of school busses required to transport school children from home to educational location as a function of different state policies concerning minimum permissible bussing distants from home to school, etc. Determine a school bus replacement and maintenance schedule to assure a higher expected level of performance reliability of school busses.

27) Lay out a scheme that would permit one to estimate the interacting effects of various federal programs as they operate in the State. Attempt to estimate ways in which federally provided funds can be used to reinforce the effectiveness of various State programs and to reinforce each other at the point of impact. Thus various programs for manpower development, vocational rehabilitation, the Welfare Administration, the Economic Development Administration, aid to secondary and higher education, the State Technical Services Act, mass transit support from Housing and Urban Development, transportation planning for the Northeast Corridor, health services, air and water pollution control, Federal Aid to Airports, and the possible introduction of new Federal offices in the State of Maryland, can be viewed jointly rather than individually as they contribute to or retard the achievement of the goals for the State.

28) Provide a means for improving inventory control, class scheduling, maintenance of buildings, etc. at the University of Maryland and other State-financed educational institutions.

29) Develop a state-wide information system that would permit access by policy makers and legislators to information concerning the operation and performance of state programs on as early and accurate a basis as possible.

30) Create expected transportation demand models to estimate the need for future state highways and bridges and determine the location which, when added to the existing transit network, would provide for maximum time-cost-convenience transport of people in the state.

31) Develop models that would permit an estimation of the level of service that could be provided by various functions when conducted at a State level, at a County level, and at the level of towns for other local jurisdictions.

32) Develop a linear programming procedure that would permit mobility of teachers throughout State jurisdictions so as to provide for a constant flow and interchange of ideas from one location to another.

33) Develop a procedure that would permit the comparison of the costs of training newly hired individuals with the costs of providing increased salary levels to existing state employees.

Although such a list is in itself highly suggestive of opportunities for the application of relatively well-tested operations research procedures with rather heavy mathematical underpinning it falls somewhat short of providing a recommended program of research that might lead to the greatest chances of immediate improvement to state operations and which might insure the viable growth of operations research.

It has been the corporate experience of nearly every operations research group in the country that the initiation of an operations research team into problems that are primarily mechanical in nature--inventory, production control, maintenance of equipment, and major item replacement--are most likely to be those kinds of projects in which an analyst who is relatively untutored in the folklore of an agency may provide the greatest return to his employer in the early years of his work and at the same time educate himself into the facts of the organization that he is serving.

If, therefore, these lessons are to be taken seriously and it is the suggestion of this commentator that they should be it would be important for the State of Maryland to select at a minimum one or several problem areas that are primarily mechanical in nature and to proceed to assign bite size problems to its operations research analysts as a starting point.

It is undeniable that the creation of a relatively large data base which probably will end up being computerized is an inescapable end product for the future. It is probably undesirable at this stage of development of management improvement in the state of Maryland to make the extremely large investment in computerizing a total data base for the use of the state. Current programs to provide data bases in the Comptroller's office, the State Roads Commission, and the cooperative efforts of the State Police should of course be continued and developed; a major statewide total information system such as was proposed to the state of California appears to the present commentator to be an investment which would be illadvised on the part of the state of Maryland at this time. Any information system that will be developed--as it certainly will--should be generated on the basis of identified need for information catagories and related to the economics of the collection of such data. The determination of the kinds and nature and comprehensiveness of the data that is required to support good management decisions will be determined after and not before the development of procedures for determining how management decisions might be improved through the introduction of "rational" calculating procedures. It has been the uniform experience of nearly every major computerized information system that the creation of the data base has entailed major difficulties with respect to the relation of that information to the questions that are placed to the data base. It is a nearly universal experience that the questions that are placed to the information system are modified to accomodate to the devices employed in establishing the data system rather than the other way around. It is therefore recommended that the state of Maryland busy itself with substantive problems and regard as immediately (but not indefinetly) postponable the creation of a major State-wide data system. Now, however, is the time to require that analysts note the relative ease of acquiring and be required to identify those factors bearing on the substantive problem that appeared to dominate the determination of the optimal answer. It should be a requirment of every operations research study that at least a very simple sensitivity analysis accompany the provision of the preferred strategy. Although this is an article of faith and generally accepted good scientific procedure it is one of the principles that is violated more frequently than any other except one. The principle that is violated more frequently is the explicit acknowledgement and listing of all of the identifiable assumptions that underlie the analysis and the identification of the extent to which modifying those assumptions would change the nature and direction and extent of the answer that has been generated by the analysis.

A. Inventory Studies.

As has been observed previously, one of the areas in which relatively noticable improvements in the total cost of maintaining inventories of materials and supplies procured and stored is in the extension of inventory control methods still further into the operation of state purchasing practices. In this kind of calculation, the gains are to be expected from considering the total costs that are entailed in procurement, storing, and issuing of supplies when taken together rather than separately. The minimum cost of operating an inventory is achieved as a result of striking a balance between minimizing the costs of storing and the costs of procurement. In this situation the costs of storage increase as the amount ordered increases; by contrast the cost of ordering which exhibits characteristics of being relatively constant regardless of the amount ordered at any one time, would over an extended time period decrease with increasing order size. Accordingly the two costs are pulling in opposite directions, and the problem is to determine that ordered quantity that strikes the happy balance between the extremely large ordering costs for small quantities on the onehand, and the extremely large storage costs for large quantities on the other. Modifications of a rather straight forward nature can be made to account for such things as quantity discounts in purchase prices and the inclusion of special penalties that accrue because of shortages of supply at the time a demand is placed. Similarly, modifications to reflect long order and shipping times are easily includable, as are calculations intended to reflect the limitation of warehouse space and order-filling personnel. It is also possible to include factors relating to seasonal variations in prices. If it is possible to estimate the contrast between future and past demand, those too can be included. The problem becomes very complicated and normally requires computer assistance in the following circumstances:

1) It is necessary to consider the cost of operating an installation in which many items of supply are stored, rather than a few.

2) There are multiple storage locations with reinforcing and cross shipment capabilities from one supply location to another.

3) There is considerable interchangeability among various items of supply including repair parts, major assemblies, and large items.

4) Repeated calculations to compensate for rapidly and severely fluctuating demands are necessary.

Normally the biggest difficulty associated with the economic order quantity calculation is the inability to forecast future demand. Normal devices involve relating supply demand rates with densities of pieces of equipment for which the supply is intended, frequency of maintenance schedules, expected equipment replacement dates, etc. Very frequently the determination of demand reates for the future with respect to items of supply in which those demand rates are variable with the age of the equipment being serviced require rather extensive and detailed item by item supply histories. There is also the difficulty that the experienced demand placed on a supply system reflects orders that are placed on the supply installation, and not necessarily those items of supply that are actually required. For instance, one is frequently confronted with the choice between repairing or replacing an item of equipment and the determination is as much a matter of expediency as it is an economic one. Demand rates predicated on usage are therefore subject to such things as the workload on the maintenance system, anticipated modifications in major usage patterns and even the personality of the individual who sets the requirements for performance.

Among the locations in the state of Maryland for which there would appear to be the potential for pay-off in the application of economic order quantity formulas and other procedures related to inventory management one would include the stock piles of materials and supplies used by the State Roads Commission, and the ordering of materials such as coal and supplies such as tires for vehicles. Finally, it is entirely possible that some modifications to the supply ordering procedure in the County and State educational institutions would profit from a check to determine whether the procedures developed in the United Kingdom would yield similar gains in the Maryland educational supply system. Some calculations of economic order quantities are already in use in various ways within the state procurement system so that the application of economic order quantity procedures represents more of an extension of existing arithmetic rather than the introduction of a novel approach.

B. Equipment Replacement and Maintenance.

Possibly one of the largest pay-off areas for the immediate application of mathematical techniques of operations research lies in the calculation of what has come to be known as the economic service life of a piece of equipment. Although there is considerable justifiable pride in a vehicle fleet that is substantially modern, this satisfaction in appearance as well as increased reliability is achieved, of course, at a price. The mathematical procedures of equipment replacement policies will identify the extent to which additional long-term costs are incurred in the state of Maryland whenever the policy decision is made to modernize an inventory. The concept is basically similar to the economics of the ownership of the private automobile in which the initial purchase price of the vehicle represents a rapidly deteriorating capital investment so far as trade-in value is concerned. For items whose maintenance costs increase with age or usage, the economic service life calculation is based on a combination of the number of years over which the capital cost of the piece of equipment can be amortized, balanced with an increasing maintenance cost. Application of such formulas is relatively straightforward even in cases where extensions of the following sort are required:

1) Discounting of capital investment costs into the future.

2) Improved performance achievable with newer vehicles, even under conditions in which two new vehicles may perform the services previously achieved by three older ones.

3) Inclusion of time out of service with penalties attached to duration and frequency of out of service events.

4) Unavailability of repair parts to service the equipment.

5) Quantity procurement discounts.

As in the case with inventory calculations one of the greatest deficiencies in operations research procedures related to the replacement calculation is the difficulty of associating a true maintenance cost as a function of age, extent and condition of use, degree of prior maintenance, relation between preventive and corrective maintenance, and the capacity of the user of the vehicle.

Replacement calculations can also be made using a relatively similar logic but a somewhat different approach for items of equipment whose failures appear to be more random in nature.

Replacement calculations become highly complicated and probably require the assistance of a computer when a total cost balance is sought among major item replacement, the availability of a technologically improved item and the entailments of a partially filled supply system.

A similar logic can be applied to the calculation of an optimal maintenance procedure on State, County, and inter-state highways. In that situation one determines the relative balance between the cost of a relatively uniform maintenance schedule on a preventive basis and the response to corrections that are required when deficiencies manifest themselves. Again such calculations may be based on least cost, minimum time out of service, or time out of service weighted by the number of users. In practice the latter calculation is very seldom made on a systematic basis. The availability in the state of Maryland of a sufficiency rating for section of the highway system suggests that it might be possible to make a calculation whereby the greatest volume of traffic could be run over the highway system with a given level of sufficiency over the total network. Considering the density of usage, determine the budget requirements to achieve that level of overall sufficiency for a given fraction of the time. One could then proceed to calculate the relation between a given budget level and the resulting choices of balanced sufficiency in the State's highway system. At this point a relation between scheduling procedures and maintenance economics becomes rather apparent, in that one could construct minimum travel interference schedules for sections of highway that form part of a longer origin-destination link.

Existing calculations in the State Roads Commission made on digital computers suggest that the introduction of such calculations would, as in the case of inventory control, represent an improvement on the state-of-the-art rather than the introduction of a total procedural novelty.

C. Linear Programming.

Included in this rather comprehensive cageogry of operations research techniques and applications must be included such things as the assignments of workers to tasks, the determination of a least cost origin and destination shipping procedure, input-output models of the State economy, and the calculation of a least cost fertilizer program for state crops, as well as the more traditional problems of a more complicated nature in which scarce resources, each having a pay-off function, are allocated so as to maximize the total pay-off from the use of these resources, when subject to stipulated constraints.

In the case of linear programming problems the solution of nontrivial problems generally requires the use of a digital calculator. Fortunately linear programming software programs exist in the program libraries of most large scale digital computers. In the case of the Computer Center at the University of Maryland this list is extended to include linear programming, nonlinear programming, quadratic programming, integer programming, and various versions of the transportation problem (moving supplies at least cost or assigning people to tasks at least cost.)

D. Queueing Theory.

Queueing theory is an approach that calculates the expected number of people, things, or activities waiting to be serviced at a congested station. The determination of a least cost or maximum performance strategy is done in conjunction with the queueing approach, which simply estimates what the expected condition of the waiting line will be whenever the people arriving to be serviced appear in a probabilistic fashion and/or when the service given to them is subject to variability.

In all but the simplest situations the use of queueing theory involves recourse to a computer, and in situations that are only moderately complicated abandon a straightforward mathematical analytic approach in favor of a simulation which will be described in section E.

Queueing situations arrise in state of Maryland in the following ways:

1) Calculations of congestion at toll facilities on highways.

2) Calculations of congestion at berths in the port of Baltimore.

3) Calculation of congestion conditions under situations of increased usage at landing facilities at airports.

4) Determination of the number of lanes of bridge required.

5) Congestion at tobacco auction locations, and at county grain elevators.

6) Determination of the number of service stations required in welfare offices and in the manning of medical facilities.

It is interesting to note in passing that the representation of the flow of water in a river can be alternatively described as an inventory condition, as a queueing situation, as well as in the more traditional hydro-dynamic flow representations.

Although there would be some interest in calculations related to queueing in the state of Maryland the immediate pay-off of a demonstrable nature is likely to be a little less evident than in the case of solving problems of the A & B variety described earlier. It is also the case that general purpose computer programs for the solution of queueing problems are not available in a general way. Most such programs need to be coded on a special purpose basis, somewhat in contrast with the condition relating to previous mathematical methods. Data difficulties have been less severe in queueing situations than in the procedures described.

E. Simulation.

It has been discovered that whenever a straightforward analytic representation of the problem under study is not immediately apparent one normally has recourse to a device known as simulation. In this approach the faith of the analyst lies in his belief that his ability to describe the operations of very small events will bear fruit, when those small events are connected in meaningful ways to lead to a calculation covering the total system. In a simulation most of the analytic constraints that are required as simplifying assumptions to facilitate the mathematics of solving a classical formula can be relaxed. It is therefore possible to introduce far more variations in the performance of a system in a simulation procedure than in an analytic procedure. Simulation developed primarily as a result of the historical investment of the Department of Defense in making the War Game by competing commanders be reduced to an explicit form so that a computer could either play out many battles on the basis of a number of different prespecified conditions, or would make auotmatic calculations of the results of decision made by the commanders, and confront them with the answers so that they could then proceed with their next decision. The difficulties with the simulation are, of course, the direct consequence of the complications built into the calculating procedure. It becomes very difficult to determine why a given favorable result occurs, or to identify that factor which is common to all successful conclusions.

Simulations, however, have been regarded more or less universally as being excellent training devices to teach to perspective operators, practitioners and managers. They have also been regarded as particularly valuable in assisting in the structure of a process that was previously believed to be unstructured.

Thus, a very complicated inventory situation, a maintenance schedule, the operation of a maintenance garage, or the assignment of patrol vessels to Chesapeake Bay routes, could be represented with a computer simulation.

Simulations have ranged from the very simple such as in the case of the operation of an airport runway, through the moderately complex ones (such as the representation of traffic flows in the Northeast Corridor) to extremely detailed, such as in some of the Defense Departments representation of conflict situations. Simulations are almost invariably conducted on large scale computers. While they are especially appealing, they normally develop into very large, relatively immortal groups of people who are capable of generating an almost insatiable demand for operating data.

In very much the same manner, as this commentator has suggested, care and caution in the creation of a large scale, state-wide information system, he would also urge that simulations of certain operations within the State are probably inevitable and are certainly desirable in the future, but they represent in all likelihood an undertaking of a size greater than that which would be easily programmed into the State budget at the present time, and which most certainly would have demonstrable payoffs measured in the mid-term future, rather than within the first year or two of its operation.

Nonetheless, some of the appeals of the gaming situation are so intense and the opportunities for taking advantage of the easy communication characteristics of a basically human simulation that one of the major suggestions of Section IV will be that the State of Maryland should exercise substantive leadship among the States in the creation of a State-management game to facilitate the joint collaboration of agencies of the State.

F. Scheduling and Sequencing.

One of the more notorious recent techniques is that of the PERT procedure (Program Evaluation and Review Technique). Basically, this activity consists in the identification of all the chronologically connected sequences of activities that lead from the initiation of a project to its completion. Associated with this identification is a statement concerning the interdependence of the events and their expected elapsed time and/or cost. The layout of these events in a diagram and the addition of the time and cost estimates permits one to calculate the shortest total elapsed time from the beginning of a project to its completion, and to identify those activities that are more critical in determinging total elapsed time than others. Simultaneously, events that are postponable and which represent opportunities to make additional personnel available for other tasks appear in bold relief.

PERT diagrams become useful when there are more than 20 to 50 identifiable operational activities that need to be undertaken and which ca be defined with a significant degree of separability from antecedent and subsequent events.

It is possible to solve a moderately complicated PERT calculation by hand. Computer software has been developed to permit computer resolution of larger calculations, and to include explicitly variability in the elapsed completion time of any specific task, For example, the same computer program library at the University of Maryland has available a PERT/TIME software package, permitting one to analyze a network of up to 2,800 events.

The literature on PERT charting and analysis is relatively easy to understand, and the DOD/NASA PERT Guide represents a useable approach for the practitioner. It is entirely possible that extension of existing scheduling procedures for construction and maintenance of highways and of any public building might be improved through expanded use of PERT charts.

Still another form of scheduling is possible. This kind of scheduling applies to the determination of a classroom schedule assigning students to teachers. A procedure of this sort has been developed over a number of years at various universities, and is now in use in the University of Maryland. It was applied this fall to this classroom sectioning problem for the university's new Baltimore campus. The procedure at hand specifies the maximum classroom size for any given section of a course. The various possible times of meeting of the schedules and an operating procedure to assign pupils to sections in accordance with a logically possible schedule are given in advance.

Scheduling of classes in this way is a possiblity very shortly after the last student enrollment card has been received. There is no reason why the procedure should not be extended to include considerations that would modify schedules to assure that students who wanted a relatively condensed schedule could achieve one, and that those who had other requirements could also be introduced through an iterative procedure. It would probably be possible to determine substitutabilities in student assignments to classrooms so that the scheduling which is now performed on a first-come-first-serve basis would make possible to remove an early enrollment who had schedule flexibility in favor of a later enrollee for whom the time in question represented the only possible solution for him.

Such scheduling procedures could be applied to situations in which group activities such as school children on public tours or the administration of group therapy in hospitals could be programmed.

G. Traffic Flow.

One of the rather well known procedures that has become part of the operations researcher's lexicon is that of traffic studies and its associated origin and destination surveys. Primarily under the stimulus of Federal support, activities related to traffic studies and the collection of information on origin of destination are relatively routine in many locations Maryland has performed a number of studies in these general directions. It is probably sufficient to notice this stage of development that an extension and improvement of existing procedures is the indicated strategy.

Among improvements that are possible for Maryland are further associations with the traffic studies being conducted in the Boston-Washington Corridor by the Department of Commerce, so that trip segments passing through Maryland but originating in different locations can be regarded with greater care than is now possible. Futhermore, increased communication among the various Metropolitan areas transit commission studies should be encouraged, inasmuch as each study seems to develop certain specialized abjectival techniques that could well be adapted to other studies. On the average, the researchers in these metropolitan area studies are moderately well informed concerning the state of progress of each others work, so that the impediments to collaboration are less severe than might be expected.

When one makes studies projecting future travel demands, the basis for doing so is very shaky, and additional developments in depth relating trip generation and the criteria for split among modes of travel needs to be searched more thoroughly than has been in the past. It is possible to incorporate novel and imaginative modifications to existing O-D surveys in Maryland that could assist still further in forecasting future travel within the State.

Clearly, the matching of highway systems between one jurisdiction and another is a pressing consideration when trip segments connect the two jurisdictions, or are scheduled for development or maintenance at times that would result in only partial service to those travelers. This is particularly true in Maryland, due to its situation in the chain of metropolitan areas, and due to the rather startling modification in the pattern of opportunities available to travelers in the State now through the introduction of beltways.

H. Location of Service Centers.

One operations research procedure that is frequently associated with the inventory problem is the determination of the number and location of warehouses and service centers that should be installed to provide maximum exposure or service to customers. The situation arises in Maryland when one attempts to estimate the number of maintenance garages, the number of supply locations, the preferred location of new school buildings to service new populations, the preferred location of recreational areas, etc. Some calculations have been conducted over the past several years applying this warehousing technique to the determination of the best location for new post offices by the Post Office Department and to the determination of the location of Social Security District Offices so as to provide the best level of service to the public. Needless to say, the same application could be made to the determination of welfare agencies in the State and in the location of many State facilities.

Of particular interest in the past several years has been the development of the warehousing model to the determination of procedures to permit political redistricting to be calculated on a computer. This redistricting specifies a total number of seats to be provided, and the computer then proceeds to determine the boundaries of a set of possible redistricting configurations in search of that configuration that will provide relatively balanced population among the different districts.

The procedure has been applied in Delaware and is being considered for application in Connecticut. Various attempts to expand the requirements placed on this calculation to include the maintenance of existing balance between the two parties for the next election have been proposed but not applied. The redistricting calculation requires a computer for any relatively moderate size number of districts.

I, Computer Software.

Among the computer procedures that are available in the library of computer routines at the University of Maryland are the following:

1) Linear programming.

2) Job-shop simulators.

3) Various games.

4) Game theory.

5) General problem solvers.

6) Schedulors.

Various of these examples have already beenmentioned the PERT/TIME calculation and the transportation problem, for instance. Among still others that are available include transportation problems in which the cost matrix may grow as large as 10,000 cost elements, and another which permits the introduction of as many as 10 columns (destinations) and 1,190 rows (origins or tasks to be assigned).

There is also a DYNAMO computer modelling procedure in the software package that permits representation of such things as flow of river water through a basin and subject to fluctuations in time. This procedure has been employed in a variety of applications, including one to the Susquehanna River Basin.

There is a non-linear programming package in which calculations are made subject to linear constraints. There is also a quadratic programming package in which the number of prime variables and the prime constraints taken together must be less than 508, and the maximum number of entries in the matrix is no larger than 6,000. Finally, there is an integer programming software package that permits the solution of problems involving up to 120 constraints and up to 300 variants.

The cut and fill calculations, including representation of grade lines, is already conducted by the State Roads Commission. Extensions developed in the operations research fraternity to include linear programming techniques for determining a least cost highway route including the engineering calculations of cut and fill involve extensive computer work. While appealing as a matter of principle, this may prove to be difficult as a matter of practice.

Among the calculations that might well be made concerning the number of service stations would be the number of cement testing facilities required to accompany the introduction of a new highway. In that situation, the value of time is a more important concern than the dollars that are required to provide the testing. Since the passage of time represents a large amount of productivity for a cement laying machine, it becomes important to provide a relatively continuous test procedure. New methods of tests probably should be developed. This, however, is the kind of activity in which operations research would probably play a lead role.

Finally, it is apparent that estimates of future traffic volumes need to be included in the program planning for future highway maintenance, since the volume of road maintenance activity is severely dependent upon the amount of traffic to which the road is subjected.

Each of the types of operations research described in this section could be performed either by an in-house team as employees of the State of Maryland, could be performed under contract to a commercial or non-profit firm, or could be given in simpler versions to university classroom problem-solving situations. Because of their similarity to procedures outlined in textbooks, some of them represent an easy transition for university students who subsequently may develop an active interest in temporary or permanent employment with the State. Beyond any doubt, students are interested in practical projects of the sort described above, and the State should capitalize on the availability of two universities who teach operations research within the State as well as others in the Metropolitan Washington Area, and provide opportunities to expose both students and professors to the interesting problems in determining what optimization means in the contest of the operations of a State.

IV. PLANNING.

As the earlier military and industrial operations research groups became more proficient in the solving of problems that were basically mechanical in nature, they rapidly discovered that the issues that prompted the existence of the problem in the first place had far broader implications than had been originally suspected. These operations research analysts accordingly became moderately proficient in the manipulation and appreciation of the broader issues of policy and interaction with other problem areas. Indeed, it soon became apparent that one of the best ways in which to use a well-experienced systems analysis group was to enlist their assistance in making long-range strategic forecasts and in comparing alternative strategies per the achievement of the goals of the organization. In rather highly sophisticated OR organizations, such as the RAND Corporation, the analysts found themselves raising questions concerning the selection and preferential choosing among various goals of the organization, and distinguishing between those goals that they had and the goals that they should be pursuing.

The problem of interaction with other programs has always been one of intense interest in the field of operations research. Reference to such simple models as the economic order quantity calculation for inventory control purposes symbolizes the fact the minimum cost calculation refers to two functional activities that are inter-related. The economic order quantity calculation is one of making it possible to integrate the efforts of two separate institutions - the procurement and storage functions - to the end that both were serving a common criterion, rather than opitmizing each activity separately. Indeed, it is frequently argued that one of the best contributions of the operations research fraternity is its ability to elicit discussion of major substantive issues and to focus the attention of the affected decision-makers on the main structural logic of the institution's total plan.

Within the context of a possible operations research program that would be proposed for the State of Maryland, the single activity that probably would represent the greatest total contribution of such an OR program would be the creation of a vehicle that would permit the joint consideration of the plans of the separate agencies of the State Government, to the end that each organization is enabled to view the consequences of its own particular planning process in the perspective of the interactions of the plans of other departments.

The purpose of such an exercise would be to permit the various agencies of the State Government to lay out, over a period of years, the expected sequence of activities they would propose to undertake. The interactions among these various plans would then be drawn into rather sharp focus. For instance, the long-term plan of the Department of Economic Development to stimulate the growth of industry and reduce unemployment in the State will have natural consequences for the State's road-building program and the public facilities that must be planned for by the State Planning Department. The State Planning Department's proposed course of action, similarly, would indicate those conditions that are maximally conducive to the encouragement of desirable industries to move into the State.

Each of these projections would then be coupled with the revenue-estimating procedures of the Comptroller's Office in its Bureau of Revenue Estimates to provide a total forecast of the anticipated long-term budgetary constraints that could be expected within the State, and to note explicitly the capital and maintenance investments that will be required for future budgetary action according to each plan of action tested.

Further advantage of such an interacting procedure would arise if, along with the development of each of the plans, provision is made for explicitly noting the social costs that are consequent upon each decision, such as further contributions to air and water pollution, traffic congestion, and general enhancement of the intellectual and cultural resources of the State.

The management game discussed in the simulation section, bears significant promise of an ability to merge the findings of the various purposive elements of the State to the end that a commonly understood set of final goals and perspectives is available to all. The development of a management exercise for the State of Maryland would mark it as having leadership position in a totally new area of application, and one of very significant promise in the area of the use of the management sciences for the improvement of the operation of the government of the State.

Such a management game could be constructed around a number of scenarios. One scenario, for instance, could present the conditions in which there is a continuation of the expected growth trends in the State of Maryland. Each Departmental player, beginning with a simulated current year condition, would be presented with his appropriated budget for that year, and instructed to execute the program that had been laid out for himself. He then would be asked to provide estimates of his intended actions over various future time frames in whatever degree of detail he would care to specify them, and to notify an umpire group of his budgetary needs. The umpire group would calculate the hypothetical conditions at the beginning of the next year, including the estimate of the revenues that would be generated. New tax policies might be created and submitted to a player who represents the Legislature for determination of a new tax structure if any. Another player, representing the public of the State of Maryland, would act to observe the consequences of these actions and represent the sensed needs and reactions of the people of the State.

Yet another player would represent the activities of the Federal Government. That player would introduce opportunities for taking advantage of Federal programs for the achievement of goals and with supplemental income for the consideration of the various agencies of the State. The implications of matching fund programs would then be added to the considerations of the players and decisions made in response to them.

Yet another player would be required to operate as if he represented county and local governments, inasmuch as a large fraction of the operations of the State of Maryland center around the administrative units that are less comprehensive than that of the entire State. An expanded version of such a game might have representatives, for instance, of each of the six regions designated as the sub-regional affiliations of the 23 counties and Baltimore City.

Finally, inasmuch as the development of the State of Maryland is achieved by the collaborative actions of government, industry, and the populace, there should be a representative, serving as a player, to present the actions that could be expected to appear at the initiative of the private sector of the economy of the State of Maryland.

There is yet one other family of players that should be introduced in such a management game. These are the players that represnet the operations of surrounding and contiguous states. The activities of those States provide opportunities for collaborative efforts, and they introduce constraints and contrasts that serve to modify the decisions of Maryland.

Such a game would prodeed through enough time periods to permit an estimate of the indicated effects of this interaction.

Under ideal conditions, such a game would be repeated using a number of different scenarious that could correspond to various environments in which the State of Maryland might find itself. For instance, an accelerated emergence of the State of Maryland as a leading national center for research and service industries is one possible course of events. An alternate scenario that would represent the State of Maryland as becoming increasingly attractive to industries that rely heavily on water resources and have difficulties avoiding pollution problems represents another.

Still further scenarios will be generated as the result of player actions. Examples of these, of course, might be the discovery of serious deficiencies in future State revenues, and the requirement to assess the expected consequences of several revenue-producing strategies. Thus, for instance, one might carry out an exercise in which the pressure for tax revenues causes a county to determine that it will permit or encourage the growth of manufacturing industries instead of a traditional policy of remaining primarily residential in nature, and comparing such a strategy with an increased income tax, etc.

In addition to its value as a communications vehicle and its contribution to the substance of the State planning itself, there is another set of untilities that should be expected of such a management exercise, and this is in its training aspects. For purposes of training young supervisors who have a larger potential future within the state government, such an exercise draws to their attention the manner in which their decisions affect the environment of decision-making in other agencies, and the degree to which they are dependent on others. It indicates those items on which coordination is to be sought as a matter of importance, and those in which the decision should be primarily theirs.

Yet one more example of training value lies in the ability to use the exercise as an educational aid, both in training university students in the nature of State government, and in classroom exercises in high school social science classes.

An example of joint training-communication applicability of the exercise would be in citizen action groups, where it is important to communicate some of the interaction facets of issues that are raised for citizen comment and vote. Such a training exercise should be regarded as potentially one of the most fruitful means of enhancing the degree of enlightenment of an already moderately well-informed electorate. From the State management point of view, it might be possible to elaborate the referendum issues of substance in the context of such an exercise, to the end that the implications of a "yes" or "no" vote on an item are clearer than in some cases at present.

Finally, such an exercise can be used periodically to provide a relatively fast and comprehensive introduction to the issues that face incoming administrations and legislators from the State, and to observe in full perspective the various priority problems they are about to be confronted with. It is possible to construct a rather primitive game that should serve this kind of purpose relatively quickly, inasmuch as a fair amount of homework on some of the required background information has already been done on a piece meal basis.

Indeed, within the State of Maryland government, there is already a distributed ability, in the form of one or two analysts in the State Planning Department, the Department of Economic Development, the State Roads Commission, and the Comptroller's Office; and in the form of a small professional staff at the Bureau of Business and Economic Research, and in the form of a professor of Operations Research at the University of Maryland, to work collectively toward the creation of such a vehicle in a short period of time. Needless to say, the creation of a few months of effort, would need to be regarded as simply the first form of a final exercise to be created. The most primitive version should be pretested by university students, Maryland analysts, and some staff members to assure the maximum playability and inclusion of issues fairly for the first "play for record." It has been found as a result of the experience of groups who prepare such games that one such exercise can be created in a period of several months, once the basic issues and items of general information are uncovered. The purpose of the game--general structure and main issue communication--requires that information be presented in a simplified and streamlined form, rather than in exhaustive detail and with thousands of entries. The information-gathering and assimilating requirement is therefore truncated severely, and professional judgement coefficients can be used in place of hard numbers. Finally, in the absence of convincing numerical data, those issues can be left to the judgment of the Umpire group to arbitrate disputes and to select an answer to a difficult set of questions.

The kinds of data that are important to such an exercise are normally to be found as the stock-in-trade of the economist, and Maryland is fortunate in already having a number of projections and analyses at its disposal in this regard. The plant location data and special industrial attractiveness studies made by the Department of Economic Development is indicative of a degree of background information that is required to make a management exercise of this type successful, although a great deal of subsequent analysis and data gathering will certainly be indicated when the first few plays have become a matter of history.

Informal discussions conducted with each of the organizations already mentioned have led to an expression not only of willingness, but of rather eager enthusiasm to participate in the development of a management game. The University of Maryland's Operations Research professor has constructed a management game for illustrating these kinds of issues for the Federal Government's three week course in the newly promulgated Planning-Programming-Budgeting system (PPBS), so that the techniques of game construction are sufficiently well-understood that the initial educational process for the game developers need not be made.

In all likelihood, such a game would have two successors. The first of these would be a fast-moving, player-dominated exercise that would represent successively improved versions of the first exercise. The second would, in all probability, be a more complicated exercise, possibly at a level of geographical detail that would show each county as a separable unit, and in which population, employment, income, natural resources, and capital investment (public and private) would be calculated probably with the use of a digital computer. Such runs would inevitably be confronted with the need to compare various possible alternative tax policies, development policies, etc. These runs would involve use of the largest of the State's computers, and would generate a need for a rather extensive computer-stored background data base.

Both kinds of games, but especially the latter, would represent an ideal opportunity to stimulate university students to a further interest in professional affiliation with the State upon graduation and during the summers, both through an association with the subject matter of the game, and through classroom projects in designing the best possible computer subroutine for calculating, for example, the changing travel time of commuters on highways as a function of increased employment in a given county.

It is understood that the Comptroller's Office at one time visualized the creation of a tax model for the use of the State, but that this had to be postponed. The generation of such a model, in conjunction with facts generated by the recent University of Maryland tax study, would be a natural portion of even a simple management exercise, and would be important in a computer-assisted version of greater extent.

One issue that will inevitably arise from both the simple and more complicated game is that of measures of effectiveness of State programs. Thus, it will become a matter of discussion as to which measures of benefit to apply, and which of those measures can be associated with numerical outputs, and which must remain judgmental and disputable in nature. These issues, however, are the most crucial of all, and they are the ones that have been reserved by our representative form of government to be the prerogative of the citizens to decide. For purposes of planning a State's program in all its facets, however, the questions will arise concerning "What kinds of industries would one like to attract to the State?" Although it is an easy answer to suggest that we would like to have all the "best" (in some sense of the word) industries come to the State, it is not always clear that complete reliance on research and service industries will solve the problem. One is confronted with the need to provide the future opportunities for employee groups that have little chance of becoming successful in such industries.

In designing alternative strategies, it will be important to discover those attributes of the State of Maryland that are examples of its excellence, for example, in the quality of educational programs at the secondary level, in the high income level of the State on a per capita basis, and in the attractiveness of the water resources of the State. More than most states, Maryland has greater freedom of choice in designing its own future. It has the ability to be selective in the nature of taxes it may want to pass, and it has a multiplicity of natural foci of interest--metropolitan Baltimore, metropolitan Washington, the Bay area, the middle counties, and the west. Maryland has a higher per capita proportion of high-quality research personnel than any other state. This also means that it has a greater opportunity to create an operations research/systems analysis/econometric/multidisciplinary vehicle for advancing State goals than any other State has.

In all probability, the citizens of the State will turn out to be some of the best commentators on what the goals of the State should be, and will be some of the best interpreters of what the State will look like from an appeal to residency point-of-view when confronted with some of the factual outputs of the management exercise.

But there appear to be two overriding considerations in urging the creation of a State of Maryland management game:

1) A vehicle for communication among multiple jurisdictions will be available, that can be employed regardless of any organizational realignment of State agencies, and which will address itself to collectively solving State problems; and

2) A device will have been created that draws into focus the problem of being thoughtful about the future of the State, and in a way that is not obscured by unnecessary detail, but is understandable.

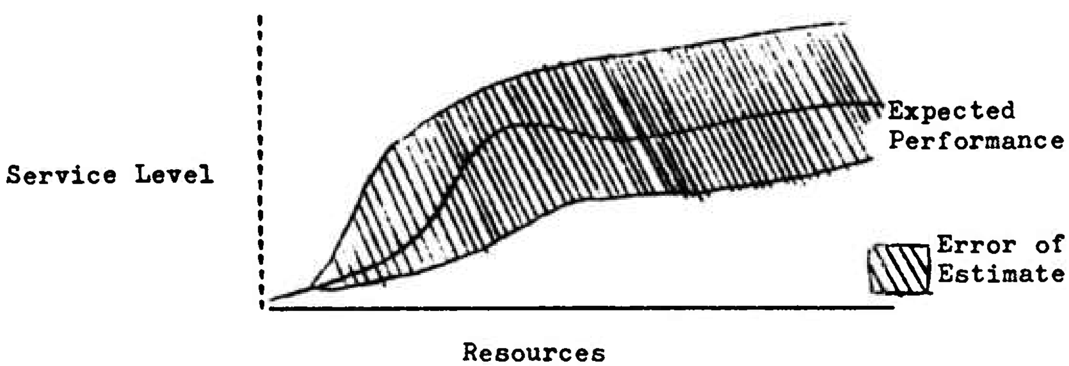
V. Budgeting Support.

One of the recent areas of support from the operations research community has been in developing means of presenting the issues in a budget argument, whereby alternatives are displayed and their expected consequences evaluated, so that choices may be modified in an improved way. The most recent elaboration of this procedure at the Federal government level has been in the PPB System described by the Bureau of the Budget in its Circular 66-3 and revisions.

The basic logic of this system is that an Agency should identify the kinds of outputs which it is expected to generate, and to calculate the dollar and other resource input needs that could be expected to produce those outputs. In order to meet the complication that multiple projects contribute to these outputs, the various inputting functions are gathered into a package that contains projects with a family relationship. Various ways of mixing these projects are identified, in search of the best mix of existing projects.

The next, and frequently more important, step is to identify alternative ways of achieving the same output; this requires a qualitative leap of the imagination. The packaging concept is conceived as producing a more credible basis for inducing such leaps, in that the concise definition of outputs in terms of the missions of the Agency tends to clear away the interfering confusion of subordinate issues. The organization of facts in such a way that inferences are easier and more straightforward is believed to permit a broadening of what Professor Kenneth Boulding1/ has called the management "agenda" of alternatives, thus giving the manager the freedom of inventing more imaginative schemes for accomplishing the mission of his organization, rather than having to rely exclusively on the traditional modes of execution of an historical program.

If each separable project or program could be described in terms of resources levels required as inputs to produce levels of service as outputs, a graph of the following form might summarize the relation between the two.



1/ Kenneth E. Boulding, "The Ethics of Rational Decision," Management Science, 12, February 1966, B-167.

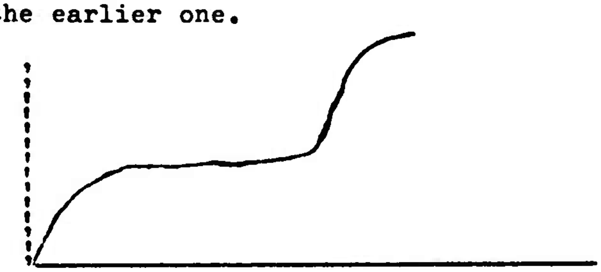
In practice, the generation of such a graph depends on either painstaking re-evaluation of existing data, or on a special study. Errors of estimate are to be expected, and should be shown along with the calcualted average value.

The calculations are repeated for as many alternative programs for bringing about the cutputs as are reasonable. This family of benefit-cost studies is made for existing and possible future modes of operation. They are brought together for final comparison in a cost-effectiveness study, which indicates preferred alternatives that are defensible on the grounds of including as many measurable expected consequences as are possible. This indication, of course, serves its prime purpose as a comparer of those factors that are amenable to such measurement, and in the hands of a skillful interpreter are often able to assist in resolving some dilemmas that transcend the simpler calculations themselves.

In benefit-cost studies and cost-effectiveness studies, a number of difficult problems inevitably arise. The first problem to appear is that of selecting some indicator of service level that is both sufficiently closely related to the "service" being described, and measurable. A large volume of current economic and OR literature is concerned with questions concerning how to select and measure these quantities, and they are frequently reduced to some "social utility function" or to some indicator of economic worth that can be related to the market place.

A second problem arises that is really a portion of the first, and this is the transformation from "service level" to "worth", "usefulness," or "utility." In this transformation, utility is related to service level in a graph resembling the earlier one.

Utility (value, worth)



Service Level

A frequent use of an experienced OR/economics team is to construct such a chart on the basis of a field study, possibly involving user interviews in depth.

A third problem in such utility studies is the determination of which level of service, or which level of utility is the proper one to be achieved. Fortunately, if the studies can be credibly pursued to this stage, it is possible to present the choice in terms understandable by all concerned-decision-makers in the Executive Branch, the budgetary debated, and the legislative discussions, all of which serve as proxy-decision-makers for the citizens. Needless to say, this concept is just beginning to emerge as a matter of practice, although a large amount of the budget backup in the Department of Defense is developed in this fashion.

One advantage of such utility studies is that the constraints or limitations on future choice emerge rather clearly. A decision to construct a Bay Bridge carries with it certain limitations on future choice, and the State is committed to a number of courses of action as a consequence. Clearly a course of positive action that solves the problem at hand, but which preserves the greatest latitude for future decisons is preferable to one that unnecessarily delimits the future.

A number of benefit-cost studies should be undertaken, elaborating on the existing procedures now used in preparation for budget hearings. Frequently such studies can assist in resolving a perennial dilemma because they require that each of several possible choices be costed and performance estimated on comparable bases.

VI. System Requirements.

One of the common slippages in initiating an operations research activity is the expectation that the organization's most difficult and perennially troublesome problems will be resolved in short order. It has been noted once, but bears repetition, that the relevance of an OR group's conclusion really begins to be significant after several (five) years of problem-solving in operational situations. Maryland has a few scattered investments in OR already under way, but they are not yet at a critical mass to provide the masterful insights that is the final target of an OR group.

A second slippage in proper initiation of an OR activity is to ignore the experimental demands of such research. Whenever possible, the proposed improved operating decision should be subjected to a test under normal operating environments. When OR groups are allowed to disengage themselves from the experimental attitude, they tend to concentrate on method and structure. While these activities are essential to maintaining the "growing edge" of the field, and should be encouraged, it is imperative that full contact with operating activities of the Agencies of the State have first priority. In an emerging science, a laboratory for testing and discovery is indispensable. State Agencies experiencing OR study activities should be prepared to assist the OR group in selecting operating components that are most suitable for field testing of ideas generat- in the studies.

Operations research studies have an insatiable appetite for data required to provide coefficients for their formulas. Such data is normally the sort that requires Herculean efforts at reinterpreting data that have been developed for accounting, reporting, legal, and control purposes. In those cases, definitional agreements concerning what is and is not includable have been made, and these are often the very items an OR study requires for its purposes. There is usually a significant overlap between the needs of the existing system and those of an OR study, and frequently the OR study will indicate the kinds of data that should be assembled on a routine basis. An evolution of the State's data system then begins to come about, and the considerations of the utility of information and the economics of collecting it jointly determine what kind of new information system is possible.

This, of course, is a continuing chicken-and-egg cycle, and a dynamically growing management system must be prepared to live with change as a fact of life. It is the argument of this report that it is a tactical error to introduce operations research through giving it a mandate either to automate existing data loads or to develop an information system. When data volumes are oppressive, and where their processing procedures are well understood, as they are in a number of Maryland agencies, the computer izing of the data system should proceed rapidly. Furthermore, the contributions of an OR analyst or an information system analyst with an OR persuasion, should be solicited, since improvements in the data system anticipating future data needs should result. But this should not be regarded as the prime activity area for the growth of OR in Maryland.

Finally, because the OR procedures so frequently involve repeated manipulations of existing and hypothetical data in widely differing ways in search of an optimum, access to a large digital computer is indispensable. At present, the University of Maryland's Computer Center represents the facility that best matches such hardware and software needs. Smaller OR problems can be handled on other digital computers now in various State agencies.

VII. Communication with the Citizens.

The concept of Operations Research developed in this report and its mode of implementation, has been derived by the notion that a new dimension of cooperative decision-making can be achieved. This dimension suggests that OR studies are made not only to serve a monolithic decision-maker on problems of immediate concern to himself, but that they should (and can) be made to serve the democratic system of rebuttal and debate.

It has already been proposed that a management exercise (game, simulation) should be developed to serve the purpose of many State Agencies who need to compare plans so as to achieve jointly the goals of the State with greater effectiveness, greater response, less expensively, and possibly some combination of all three. That exercise, as well as some selected OR studies performed for the State, could be used to expose the citizens of the State to the major competitive issues on which they have instructed their representatives (both legislative and executive) to act, in such a way that the complementarity among issues is plainly brought out. One such study, conducted by Case Institute graduate students for a Master's thesis, involved laying out the budget, revenues, and operations of the City of Mayfield Heights, Ohio, over a 50-year future time span. Mayfield Heights was confronted with the accomplished fact that a major interstate highway would soon pass through the city center, with a major interchange to be located at that spot. Among the issues that demanded discussion at the time was the choice of the nature of the community that Mayfield Heights wanted to be over the next several decades. There were those who argued that land usage should be vectored toward high-rise apartments; there were those who argued that the downtown district should capitalize on the newly-found attractiveness to industry and zone major areas industrial; and there were those who argued for an increasingly protected residential nature of what had been a "bedroom community" for Cleveland. The students calculated the expected revenues and budgets for each of these alternatives, along with the implicit need for new equipment (a high-rise fire engine), altered insurance rates, changes in bond interest rates, etc. The calculations, which were made in close conjunction with city officials, were so instructive that the discoveries were aired in open City Council meetings to the great benefit of all, and with a most convincing level of understanding on the part of attending citizens. Among the unexpected discoveries that became more clearly focussed as a result of the careful long-range plan comparisons were the questions about future urban renewal needs and major replacements in the sewage system.

It is a major suggestion of this report that the Maryland OR program capitalize on discoveries of this nature (of which there is a rather wide number in existence), and deliberately prepare to communicate with the citizens of the State using such exercises as a discussion basis. It is a moral obligation of the State to invest in developing an enlightened citizenry, and this is one manner in which the OR techniques can offer significant assistance. Through use of operationally defined calculations (in contrast with abstract logic), the imagination of citizens can be stimulated to be more creative about the goals of the State, and about the preferences for priorities among programs.

The communication process is not complete when the State-citizen link is considered, however. Similar processes are promising (and perhaps chronologically earlier) between the State and the counties, between the State and its subregions, between the Executive Branch and the Legislative Branch, and as a mode of discussion between the State and its neighbors and the Federal Government.

Indeed, one may well argue that the Federal urge as communicated to the States to develop a comprehensive systems plan of its operations can be best met with the creation of a multi-person State management and planning exercise, so that all possible Federal programs can be reflected within it.

Finally, and possibly the most difficult task, is to assure that the techniques of operations research can successfully serve to elaborate the issues in such a way that the political processes that are at work can draw meaningful inferences from them. For operations research deals with research into operations, and operations represent the world of action. It is unfortunate when the political processes are denied the opportunity to profit from the advice of a research community that has been found to be so important in an operating activity.

Substantially, then, operations research at the State level represents a curious mixture of direct application of relatively well-proved mathematical procedures and a pioneering excursion into creative areas of new ways to assist in the development of the goals, the political processes and the whole fabric of American democracy.

VIII. IMPLEMENTATION STRATEGIES -- ALTERNATIVES.

There is a rather wide spectrum of possible implementing alternatives available to the State of Maryland in furthering the development of operations research.

A) Create a central OR Group, attached at some location where access to all State Agencies is possible. Such a central group should have a minimum of ten members, possibly starting with five. A central group has the advantage of an interacting mass of analysts with comparable motivations and training, and this is an important asset to possess. A central group has the disadvantage that it may withdraw from the action problems, or may degenerate into a fractionating array of staff assignments, with the consequence that the researchers do less OR and more staff advising. Such a deterioration would nearly guarantee a postponement of major integrating studies. However, natural evolution would probably lead to the creation of a central OR group in a decade or so.

B) Augment the OR capabilities of existing agencies, including the Department of Economic Development, the State Planning Department, the Comptroller's Office, the Budget Bureau, the State Roads Commission, and the State Department of Education. Such augmentation would proceed in a piecemeal manner with the addition of one (or two) operations research analyst positions in each selected Agency. As has been indicated earlier, there is likely to be major recognizable dollar improvements associated with studies of equipment replacement and inventory control, so that such a strategy enjoys the advantage of being likely to document the economic argument for the creation of an OR capability. Such a strategy would probably postpone the creation of a central group for several years while the individuals added to the staffs performed their early studies. Although these individuals would gain the experience that a central OR group so badly needs, it would subsequently be difficult to separate them from their parent Agency to create a new group, and probably in direct proportion to the demonstrated success of the new techniques.

C) Contract work. Many excellent consulting firms and non-profits are available to perform research into State problems; the experience of the State of California is only one bit of evidence that this is so. The difficulty with an exclusive dependence on contract work is that contractors must be trained in State problems just as an in-house group must, and the contractor needs assurance of probably continued level of support if he is to be able to provide the fullest measure of contribution. Furthermore, the maximum use of a contractor's study by the sponsoring Agency requires that the sponsoring Agency be prepared to interpret and apply the findings of the contractor, and amend them where required. This, in itself, means that a contracting Agency should have good and continous monitoring of a contractor, and this probably means that some strategy similar to B above is a prerequisite to the fullest use of C. In any event, it is an excellent subalternative strategy to employ contracting firms to perform studies in areas where their competence transcends the in-house skills, and to obtain additional objectivity and novel insights.

D) University work. The State of Maryland is particularly fortunate in having one of the earliest and strongest OR faculties at the Johns Hokins University, and in the multidisciplinary collaborative possibilities at the University of Maryland. It is recommended that the State of Maryland, in a timephased sequence, adopt the following alternatives with respect to University work:

(1) Sponsor coordinated and continuing research at the University of Maryland, to involve both specific problem-solving activities and the initial development of the proposed Maryland management game.

(2) Sponsor student projects at Maryland universities and colleges, to involve professors and give financial support to students, on identifiable OR problems.

(3) Invite OR students to participate in a summer employment plan, with the expectation that good students will find projects that could qualify for support under (2) above.

(4) Send several candidates from Maryland State employees to each of the Universities offering an OR curriculum for the necessary period of time.

(5) Invite the Maryland universities to offer short-courses and executive training programs in OR to selected State employees.

(6) Provide Sabbatical employment opportunities for Professors.

In all the University-related alternatives, the advantage lies in the input of new techniques, objectivity in approach, the likelihood of finding novel ideas, and in recruiting. The disadvantages to the State lie in the fact that a University's prime concern is education, so that it is unfair to expect a University to solve routine production problems, to do research on a crash basis or to engage in a major way in activities that would erode the prime mission or autonomy of the university. Some of these difficulties would be alternated if a University-affiliated State Operations Research Center were created.

E) Rotation Schemes. In all probability, some variation of each of these implementing strategies is likely to evole. Explicit provision should be made to assure rotation of OR personnel among the various groups. The usual OR professional thrives on being confronted with a succession of different and new problems, and the advantages of retaining such employees merit the creation of a program designed to give them the opportunity of working on a new type of project without changing employers. Some OR professionals will, or course, identify problem areas in which they should establish semi-permanent or permanent residence, so that the rotation scheme should contain provisions to permit long-term stopovers. One element of the rotation scheme should be to assure that researchers have short periods (3 months to 2 years) of assignment in operating Agencies and at the field level to assure their constant updating of State facts. Similarly, they should be regularly sent to a University for a semester or two to update their analytic tool kit in this rapidly developing field.

F) Finally, it appears that a fair portion of the OR-related skills now in the employ of the State of Maryland are a direct consequence of the investments of the Federal government in the sense of their requirement for the provision of integrated State plans. Opportunities arising from Federally-sponsored programs, both individually and collectively, should be exercised to the fullest. The possibilities of creating a central systems analysis/planning activity with Federal financial support should be further explored with Agencies of the Federal government now supporting activities in the State.

IX. SUMMARY AND RECOMMENDATIONS.

The State of Maryland should initiate a program of operations research/systems analysis/econometrics/planning/multidisciplinary problem-solving in at least two ways:

1) Augment the existing, but small, use of time-tested analytic procedures of inventory control, equipment replacement studies, linear programming, and economic forecasting, in various departments of the Executive Branch of the State Government. This should be accomplished with the addition of about five operations research analysts distributed to the staffs of existing agencies, and through an increased use of the Maryland universities.

2) Develop a management exercise (game or simulation) to assist agencies to address themselves collectively to the inter-acting expected consequences of their individual plans, to the end that the goals of the State are more fully realized as a result of collective thoughtfulness about the future. The University of Maryland's Bureau of Business and Economic Research should serve as the initial focal point for this work.

The text of this report elaborates still further opportunities for the exercise of other operations research techniques.

Finally, and more importantly, a State government provides a unique opportunity to develop the systematics of the management sciences to problems that involve multiply-connected jurisdictions, the complementarity of goals, the emergence of new aspirations of man, and a direct test of the best way to turn the new management science methods to the support of the democratic system of rebuttal and debate.

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